ALTA 2018 LITHIUM PROCESSING PANEL DISCUSSION

May 2018

The panel discussion was held 25 May, immediately following the Lithium Processing Forum during the Uranium-REE-Lithium Sessions at ALTA 2018 in Perth, Australia.

Panel Chair: Grant Harman (GH), Lithium Consultants Australasia (Australia)

Panel Participants (left to right): Adam Whalley (AW), Zeton Inc (Canada); Stephen La Brooy (SLB), Ausenco (Australia); Mike Dry (MD), Arithmetek Inc (Canada); Mark Aylmore (MA), Curtin University (Australia); Adrian Griffin (AG), Lithium Australia (Australia); Adam Roper (AR), ANSTO Minerals (Australia)

***Editor's Note**: The contributions of the panel members and delegates are not presented verbatim, but rather have been paraphrased and condensed for clarity and brevity. They are not necessarily recorded in order but are grouped into major topics. Also, it is not feasible to include all contributions made during the discussions, and they are limited to some that are representative of the key points raised and debated.*

Introduction

GH (Chair), began by displaying a number of slides summarizing the lithium market forecasts to generate comments:

1. A bearish statement by Morgan Stanley that the lithium price is going to go down because SQM production in Chile is going to double by 2019 and double again by 2023, plus a contrary view by Newgate Capital Partners giving eight reasons the lithium market will stay tight and why oversupply is a figment of the imagination.

2. A diagram from EV-volumes.com showing monthly plugin vehicle sales increasing for the last three years, indicating a growing demand.

3. A very impressive list of plants apparently being built and all coming on in 2018, published by the Chinese Non-Ferrous Industry Association.

4. Published information by Orocobre showing that the 2012 projections for lithium production to be on-stream by 2016 were far higher than was actually achieved, and that in reality we continue to under-deliver but overstate the capacity we believe will be coming on-stream, be it spodumene or final product.

5. MacNulty curves showing the relatively slow ramp-up performance of lithium projects as presented in one of the Ausenco papers in the Forum, which highlights the above comment on under-delivery of new capacity.

Lithium Market Production Forecasts

From the floor asked whether is the forecasted doubling of SQM's production by 2019 is feasible?

GH (Chair) responded that he didn't think so, unless there is something we don't know, and they are far more advanced than I think. Conventional brine treatment typically involves 18 months in huge evaporation ponds that have to be dug out and lined with geochemical liners, which requires additional time. Then the ponds have to be filled and left to evaporate. So unless they are full and almost evaporated now, they won't come on stream in this year.

AG (Panel) commented that he didn't think that the forecast production increases for SQM are commercially viable in view of the change in their licence conditions. If the lithium carbonate price is over $10,000/tonne they will be subject to a 40% royalty, which makes the decision to expand very difficult. This could be why they are investing in hard-rock processing in Australia.

GH (Chair) added that when Albemarle tried to treble their licenced production there was huge opposition, and they were only going to a fraction of SQM's expanded production. The protest concerned the effect of the lagoon on the flamingos. At the last ALTA conference very reliable sources reported that that there was significant concern by parties about whether the Atacama could support the increased water pumping rate, which is considered to be currently close the limit.

From the floor asked hasn't China stipulated that one in four of their cars is going to be electric by 2025? That is going to require a lot of lithium batteries.

GH Chair commented that there are many battery manufacturers who would love to have more in the way of chemical in their warehouses to prevent a disastrous occasion where they would not be able to continue to produce. The stockholding of all the battery raw materials is relatively low.

Matt Soucie (MS), Zeton (Australia), floor referred to the slide which showed that the predicted production increase over 2012 to 2016 was far higher than was actually achieved and suggested that the current media predictions may be following a similar pattern. The people who write these articles are probably very far removed from a room like this that has a lot of technical expertise in how these projects are developed and executed over a long period of time. What has happened in the past is probably the best predictor for the future.

AG (Panel) agreed and added that the analysts probably do not appreciate how long it takes to bring these projects on stream. They may be on the drawing board now but, if you can build one in three, four, five years, you're doing pretty well. He observed that, from past personal experience, similar oversupply forecasts for nickel from nickel laterites projects were made that never eventuated. Also, in the case of lithium, the demand is moving rapidly, and if projects continue to move slowly the price will remain high.

Realistic Ramp-up Times

GH (Chair) invited comments on realistic ramp-up times. He said that a fundamental problem is that people trying to bring projects on-line tend to project an optimistic outcome in order to improve the economics. In contrast, for the Bacanoar project, it was recognised that it would probably not be possible to sell the lithium carbonate during the first year due to not achieving the required specification, and this was built into the economic model.

In response to a comment from the floor on the difference between ramp-up time for mining and direct shipping ore to China versus developing a project to process the ore in-house, he added that his comments related to processing into some form of concentrate, which would be the case for most projects.

Mark Benz (MB), MRB Consulting (Canada), floor observed that in ramp-up times you reap what you sow. The key steps are understanding the complexity of the flowsheet and the number of novel steps before undertaking the engineering, then after building the plant, applying the appropriate human resources and

expertise to get it up and going, and babysitting it until it is sustainable. Problems arising due to rushing through these steps trying to be first into market are the things that can impact the ramp-up. Also, it's the things you don't pay attention to that bite you . For example, one of the last Caron plants to treat nickel laterites, built by Marinduque Mining in the Philippines, was heavily piloted and fundamentally the metallurgical plant and unit operations, including the roasters, worked as planned. However, the things that were not piloted were the calcine coolers after the roasters. They never operated properly, and because of the layout of the plant, they couldn't be replaced, and the plant never exceeded 80% capacity at any given time. So materials handling, liquid/solid separation, these are things that are not sexy, but you must not ignore them, or if you do it can be costly.

Processing of Alternative Lithium Minerals

Herman Scriba (HS), Consultant (Australia), floor, asked whether the new lithium projects coming online, are predominantly for treating spodumene concentrate and how many are treating some of the secondary concentrates such as the micas and other minerals?

AG (Panel) referred to a broad-brush comparison of the economics of processing a spodumene concentrate containing 7% Li_2O and a lepidolite concentrate with 3.5% Li_2O to produce lithium carbonate using conventional technology. The processing costs are similar, so for the same operating cost you will only produce half the amount of product from the lepidolite. So there was no point in processing lepidolite until we saw very elevated lithium carbonate prices. However, now that the current internal market price is around $18,888-$20,000 the scenario has changed, and as a consequence, there are two major plants being constructed to use conventional technology to process lepidolite in China, the lepidolite being a by-product from the mining of tantalum. This is what has driven the ability to process some of these alternative materials using conventional technology.

AW (Panel) added that from Zeton's perspective as a supplier of pilot plants, many of the projects at the R&D stage to be commercialised in 10 years' time are actually based on treating brine, and in some cases waste materials. Converting a waste material and into something valuable is the best business model out there.

Testwork Issues

From the floor raised the issue of achieving a homogeneous mixture with acid ahead of baking. From personal experience working with rare earths in the laboratory, there are problems with homogeneity when using a pug mill or other type of mixer resulting in less than 100% activity.

GH (Panel) responded that with spodumene, achieving homogeneous mixing is relatively easy if acid is used as it tends to readily permeate into fractures, nooks and crannies formed during calcination. For this reason spraying on the acid followed by mixing is basically ok.

However, it is much more difficult with secondary lithium minerals where you are trying to get things to happen on the surface, and you try to mix two or three components. The attention to detail in terms of getting the mix right, cannot be understated as has been found in personal experience with zinnwaldite and confirmed by others. Very good mixing is required, and it is imperative to follow careful guidelines for the procedure and subsequent scale-up of the results. In his experience, the mixing time using acid is in the range of 3-10 minutes to get a good result

From the floor agreed that, as far as acid goes, the mixing is relatively straightforward.

Novel Lithium Flowsheets

GH (Chair) introduced the topic of the status of novel flowsheets such as the SiLeach®, L-Max®, and Neomet processes. He commented that he has not heard any news about Neomet for the past two years, while it is reported a demonstration plant is being built for L-Max®. He added that he would defer to AG (Panel) for comments on SiLeach®. He then asked for comments on any other processes that are moving forward rapidly, and whether the world is embracing novel technology? His own view was that progress is very slow.

MD (Panel) reported that Pure Energy Minerals is developing a selective lithium solvent extraction process for the Clayton Valley brines project in Nevada and have lodged a NI 43-101. The brines undergo pre-treatment to remove all the divalents prior to SX. The claimed major advantage is that evaporation is not required which

avoids the long lead time, eliminates the big salt dumps that prevent subsequent land use and does not denude the aquifer.

There is also a lot of information in the literature on lithium ion-sieves, which are very selective lithium grabbers. But this is in its infancy and is not going to be in production next year.

GH (Panel) added that Phase 1 of Nemaska's lithium project in Canada, which is nearing completion, features two novelties. The first is a flash calciner. The second, which was scaled up from Phase 1 experience, is a membrane electrolysis process that splits the lithium sulphate to produce lithium hydroxide and sulphuric acid.

AG (Panel) advised that SiLeach® is in the funding stage. The current emphasis is on putting together all the agreements on plant location that will be a brownfields site which provides all of the infrastructure of road, rail, power, gas, water and most importantly, a permitted tailings dam to avoid the problems associated with a new site. We are currently negotiating supply of the feed which will be from Western Australian, and we will be reprocessing the dumps at Lepidolite Hill which is one of our deposits just south of Coolgardie, Western Australia. I would like to be in a position to push the button on construction later this year; build time will be about 18 months and that would see us with first production in 2020. The facility will be a 1/10th scale pilot plant.

GH (Chair) commented that the risks for treating secondary minerals are generally considered to be high, especially for large capacity projects, and there are still lower risk projects potentially available

Effect of Boron on Lithium Processing

Arnold Getz (AG), Kelget Pty Ltd (Australia), floor as an investor raised a question about the effect of the need to remove boron on the production cost for lithium for a potential producer in Nevada whose market capitalization has rapidly increased despite the presence of boron in the ore. He also commented that, from personal experience in another field, you have to be careful not to get hung up on particular materials. If we can't produce enough lithium, whether it's the political will or whatever it is, there is going to be a substitute, so you always have to have an eye on what may come up unexpectedly.

MD (Panel) added that from his experience boron has to be removed, either by IX or SX, and will be an extra cost. However, the only reason he was able to find why it has a deleterious effect on batteries was a reference in a patent which said that lithium metal is made from lithium chloride, which is made from lithium carbonate or hydroxide. It is in a multi-eutectic bath of lithium and potassium chloride, and borates and sulphates short-out the cell.

GH (Chair) advised that he has never seen a problem in producing a sufficiently pure lithium carbonate when boron is present, and that it a cost rather than process issue.

AG (Panel) pointed out that in some cases boron can be turned into a commercially advantageous by-product. For example, looking back, FMC and SQM were basically fertilizer producers almost throwing away the lithium; but when the lithium boom came, they became lithium producers. They are not throwing away the fertilizers but now produce by-product borates and potash. Boron is an inherent component in the solars in South America, and you can actually take advantage of it, rather than it being a disadvantage.

Another example is Rio Tinto's Jadar deposit in Serbia which is one of the world's largest lithium deposits. The lithium occurs in the form of jadarite, a lithium sodium borosilicate mineral, so that boron will be a significant by-product.

Sodium Sulphate Issue

HS (floor):pointed out that the new projects will produce more sodium sulphate than the available market and asked whether there are any advances in dealing with this problem.

GH (Chair) responded that this will limit the number of plants built with the conventional sulphation route, unless membrane technology is added to salt split. Tianqi coming on line is going to add about 100,000 tpa sodium sulphate which, in his opinion, is going to be difficult to find a home for.

The other potential problem to consider is residue. Aluminosilicate from a spodumene processing can be used in building materials such as concrete.

MD (Panel) added that if you look at the brine side, the newer brine technologies are simply taking a little bit out of brine and putting it all back into the aquifer.

Potential Use of Lithium Carbonate Instead of Lithium Hydroxide

GH (Chair) said that the need for hydroxide was born during the development of high nickel batteries. Nano One has recently come out and said they don't believe that any more, and they have ways around it. They believe that they can take any lithium carbonate, even of a lower purity, and still produce marketable cathode materials. So it looks as though it is a fast evolving sector of the market. The technologies are evolving very rapidly, and he is not aware if anyone still believes that high nickel batteries can only be made with lithium hydroxide

AG (Panel) added that to a large extent it depends on the morphology of the crystals or the minerals to be produced, and it is easier to get good morphology using hydroxide than carbonate. But if you're prepared to produce a battery that has lower performance, carbonate is fine; or if you want to use VSPC technology it simply doesn't matter because you do not pass through a solid phase. Dropping out a colloid of known chemistry straight from solution is much better than mixing heterogeneous solids, trying to coat them with lithium hydroxide, then calcining, grinding and sizing yet again, which is what most people do (Editor's note: VSPC is subsidiary of Lithium Australia)

GH (Panel) Referred to a pictogram of a coarser material about 5 micron and another one at 100 nanometres shown by AG and asked whether he had seen any benefits of using the very fine material in making batteries; In particular he asked whether it resulted in a faster charge rate.

AG (Panel) said that the answer is yes. We have benchmarked against the best in the industry using like for like chemistry and we get an improvement in the energy density of a couple of percent. However, the main advantage is in quality control, being able to produce a consistent product, which is more difficult when going through a solid requiring repeated sizing, grinding, and coating.

HS (Floor) raised the issue of needing to talk to your eventual customers, the battery producers, to find out what they want, and asked **AG** for an explanation of how lithium carbonate is typically incorporated into a battery. Also, what is a typical way of combining the lithium carbonate with the nickel and cobalt?

AG (Panel): responded that simplistically the pH is raised to precipitate the metals as hydroxides. This happens over a range of pH, so it is in very difficult to precipitate them at exactly the same time. So inevitably there is a variation in chemistry from particle to particle. The product is then calcined to form a mixed oxide, ground and sized then coated with the lithium chemical, some of which absorbed into the crystal and some sits on the outside. Then it is calcined again. As mentioned previously, a better crystal tends to be obtained with hydroxide than with carbonate. However, there is still a market for lower cost and subsequently lower performance product made from carbonate.

Direct Shipped Ore

GH (Chair) asked for comments as to whether there a future for direct shipped ore, for example for shipping 1½% material from Australia to China or anywhere else in the world.

AG (Panel) said that the economics of moving material from Australia to China at that grade do not make sense. Every tonne of lithium carbonate requires seven tonnes or thereabouts of spodumene concentrate; so you would have to ship an enormous amount of ore to produce one tonne of carbonate.

GH (Chair) added that Talison has a mountain of 1½% material which they don't process because it doesn't beneficiate well, and that may be the problem with some of the other material that might be available in various places the world. He believes that another company more to the north of our state has recently gone through the exercise of looking at whether to direct ship or beneficiate, and the economics clearly indicated that for them, direct shipping was not viable, even if they could only get up to 4% by beneficiation.

AG (Panel) added a final thought: There's always a political angle and if you're here in Western Australia, support Lithium Valley and get out there and make sure you all lobby and get the best bang for your buck with respect to the research and development rebates. We've got to keep this industry going. We've got to be in the forefront. This industry is in five years' time going to be a $2.1 trillion industry, and most of it could be here in Western Australia.

Summary of Key Points

- There are conflicting forecasts for the future production and demand for the lithium market which will be significantly impacted by the large expansions announced in Chile. However, there are number of factors which may slow down or reduce the proposed expansions including change in licence conditions, possible restriction of water pumping rate, and impact on the flamingo population.
- The speed of implementation and ramp-up of expansions and new projects may be overestimated as was demonstrated by the actual figures for the period 2102 - 2016. Another positive factor for the market is bullish projections for EV production in a number of countries.
- Processing of secondary materials such as lepidolite requires a high market price to be economic if conventional technology is used. Current high prices are driving projects using conventional technology to process lepidolite in China. New technologies may result in more competitive operating costs.
- Achieving a homogeneous mixture ahead of baking in laboratory testwork is relatively straightforward when mixing acid spodumene. However, it is much more difficult with secondary lithium minerals which require careful guidelines for the test procedure and scale-up of the results.
- Novel flowsheets at various stages of development include SiLeach®, L-Max®,and Neomet in Australia, and Pure Energy in Canada. Lithium Australia are aiming to start construction of a 1/10th scale pilot plant for SiLeach® later this year, to come on stream in 2020.
- The projected new projects using the conventional sulphation route will produce more sodium sulphate than required by the market unless membrane technology is added to salt split. Disposal of residue is another potential problem to consider. Aluminosilicate from spodumene processing, can be used in building materials such as concrete.
- Lithium hydroxide has been generally considered to be necessary for battery production, as it tends to produce a better crystal structure in the cathode powders than can be achieved using lithium carbonate. However, there is still a market for lower cost product made from carbonate which achieves lower performance.
- The economics of transporting direct shipped ore to China or other countries generally do not make sense due to the enormous amount of ore needed to produce one tonne of carbonate.

The Editor acknowledges the work of the student volunteer from Murdoch University, Bryce Albertini, for providing notes on the discussion.

Novel Lithium Processes is the featured topic for the ALTA 2019 Lithium Processing Forum and Panel, which will be held 24 May in Perth, Australia.

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