Tuesday 3rd October 2017

Written Testimony of Simon Moores, Managing Director, Benchmark Mineral Intelligence

For: US Senate Committee on Energy and Natural Resources Committee

Hearing: Tuesday, October 3, 2017, at 10:30 a.m. EDT in Room 366 of the Dirksen Senate Office Building in Washington, DC.

Subject: Energy storage technologies and the supply chain risks and opportunities

Thank you for inviting me to this hearing on energy storage technologies to give my independent, market-focused perspective on the opportunities and risks in the supply chains.

Energy storage is not a new concept. We store energy in our phones, laptops and power tools every day and recall and use this energy on demand.

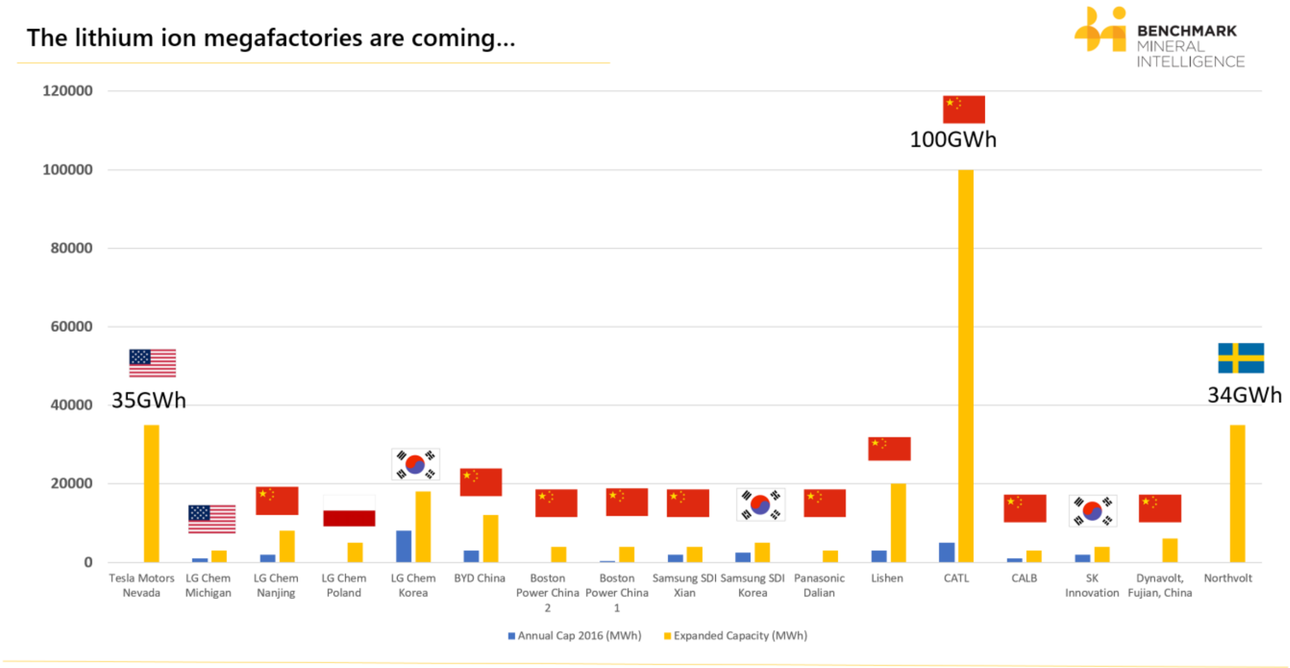
However, the widespread adoption of energy storage – most critically in our vehicles and for our homes, offices and energy distribution networks – is only just gathering pace owing to low cost, abundant lithium ion battery cells.

This trend was given impetus by rise of the lithium ion battery megafactories, a term created by Benchmark Mineral Intelligence to describe the widespread expansion of battery cell production capacity around the world. Huge battery plants are now being constructed that are an order of magnitude larger than their predecessors.

In 2014, Tesla announced their Gigafactory in Nevada with 35GWh of new cell production – the equivalent of 500,000 pure electric vehicles (EV). At the time, this was the first ever plant to have a capacity over 10GWh.

This sparked a global battery arms race that has now spread to 17 megafactories in the pipeline, 9 of which are in China and only 2 of which are based in the US. In terms of production capacity from these megafactories, China will have 64% and the US only 13%. The remainder of the planned plants are in Korea, Poland, and Sweden.

Despite this new 289GWh of capacity adding to a global lithium ion cell production of 80GWh in 2016, according to Benchmark Mineral Intelligence data, the industry is still drastically short of capacity to meet projected demand of 550-650 GWh of battery cells by 2025.



These lithium ion batteries will be targeted for use in the two largest growth markets, EV and stationary/utility storage – the two uses that underpin the energy storage revolution.

Both markets are in their infancy. However, as these applications mature over the next 10 years, the scale of application and its disruptive effect on established auto and energy industries will be unprecedented.

Pure electric vehicles – from cars to electric buses – are only entering the market place today and are all are based on the lithium ion battery technology.

Consumer choice of pure EVs, vehicles that are 100% battery powered and where a combustion engine plays no part, are beginning to become numerous. For example, 2017 saw the launch and/or rolling out of the pure EVs of Tesla's Model 3, Chevrolet's Bolt and Nissan's new LEAF.

These are the first sub-$35,000 pure EV offerings for the consumer and has ushered in the era of the semi-mass market EV.

As we approach 2020, we are seeing every single major auto manufacturer announcing aggressive pure EV plans all based on lithium ion.

Volkswagen Group, Daimler/Mercedes, Toyota, and Honda, for example, are all planning selling lithium ion powered EVs in the millions of units annually post-2020. Meanwhile, the trend in e-buses has also started to gain traction outside of China due to the efforts of California-based Proterra. These e-buses have lithium ion batteries up to ten times the capacity of EVs.

The second major energy storage trend is one of stationary / utility storage. At Benchmark, we see the utility storage sector where EVs were in 2009: a limited number of installations around the world with industry momentum increasing.

Rise of lithium ion technology

The lithium ion battery is not new technology; however, its widespread commercial use has until now been limited to portable personal technology (cell phones, laptops, power tools), hybrid vehicles and a handful of EVs.

Lithium ion technology being used is not one battery but a selection of different lithium ion types or chemistries; the ones of note are:

- Lithium Cobalt Oxide (LCO) used in portable technology
- Nickel Manganese Cobalt (NMC) used in EVs and utility storage devices
- Nickel Cobalt Aluminium (NCA) used in EVs

These chemistries are all lithium based, despite the naming convention, and the critical raw material inputs are: **lithium**, **graphite**, **cobalt** and **nickel**.

While other metals are also used in a lithium ion cell such as copper and aluminium, the speciality nature of the afore mentioned minerals and metals increases the complexity of the supply chains. It needs to be clearly understood the need to process these elements into a battery grade chemical derivative product that is tailored for each customer.

In short, we are dealing with niche, speciality chemicals and minerals rather than commodities. The biggest challenge for this handful of specialities is scaling the supply chain from the mine to the battery plant in time to meet demand from the auto manufacturers.

Lithium: a speciality, volume problem

Lithium, the highest profile input into a lithium ion battery, is sourced from Chile, Argentina (brine extraction) and Australia (traditional rock mining) and is also processed into battery grade material in the US and China.

Lithium carbonate and lithium hydroxide are the base chemicals that the battery industry seek, the industry's demand profile is increasing 10-fold in a 10-year period. Demand pressures from the battery industry have already forced prices of these chemicals up four times in the last two years and it is a rising price trend that is continuing today.

In 2016, lithium carbonate equivalent (LCE) used in lithium ion batteries equated to 75,000 tonnes. By 2025, battery demand will be 550-600,000 tonnes. A complete evolution of the industry is required to take lithium from the niche into the mainstream.

Not only does lithium need to scale its extraction capacity but also its battery grade processing capacity to meet the requirements of battery customers – an additional, specialised step.

The US has two major players in the lithium industry: Albemarle Corp and FMC Lithium are among the world's largest lithium producers sourcing predominately from Chile and Argentina brine operations, respectively. Both producers have processing capacity in North Carolina.

In terms of lithium resources, the US produces lithium chemicals from a small brine operation in Nevada. Clayton Valley is one hotspot of exploration for new lithium brine together with the Arkansas Smackover oilfield brine resource. Recent hard rock exploration for spodumene in North Carolina has also occurred in a bid to secure domestic US lithium.

Graphite: an anode processing problem

Graphite anode, the largest input into a lithium ion battery in kilograms, has a similar scaling issue. Graphite in batteries comes from two sources, naturally mined flake graphite and synthetic, man-made graphite.

In 2016, graphite anode used in lithium ion batteries equated to 100,000 tonnes. By 2025, battery demand will be 780,000 tonnes.

Natural flake graphite mining is dominated by China with 62% of global production in 2016, a position only Brazil can compete with producing 23% of the world's 650,000 tonnes. This flake graphite is then sent to spherical graphite plants – all of which are presently located in China – to be processed into anode material.

Just under 60% of the lithium ion battery industry's anode is derived from natural graphite with synthetic graphite – produced from graphitizing petroleum coke and tar pitch at very high temperatures – accounts for ~40%.

Due to lower production cost, environment and CO_2 impact issues, and ease of scaling supply, battery customers are trending towards using more natural graphite anode in their cells but are still blending with synthetic graphite. The knowhow in blending different anode materials with differing raw material signatures is a skill and intellectual property that will separate out the leaders of the pack.

While large flake graphite mines are being developed outside of China in Mozambique, Canada and the US, processing capacity to make anode material is still lagging. The US has two graphite companies seeking to mine and process flake graphite for battery grade material in Alabama and Alaska.

Cobalt & Nickel

Cobalt is the second highest profile battery raw material mainly because 64% was mined by the Democratic Republic of Congo (DRC) in 2016 and because China dominates the refining step in the supply chain with 57% of global capacity.

Headlines regarding cobalt mined illegally in DRC have dominated the cobalt discussion despite the portion of illegal material in the market being relatively low and under 10% of global supply which was 93,000 tpa in 2016.

However, illegal cobalt in the supply chain has greatly concerned end users of batteries mainly owning to the corporate social reasonability impact on their businesses.

Major end users have moved to try to eliminate illegal cobalt from the supply chain and this has opened opportunities for developers of new mines based in US (Idaho), Australia and Canada that could guarantee the provenance of their raw material.

In addition, cobalt's geological occurrence as a secondary mineral to nickel and copper means that its produced as a by-product of these metals. Only one small primary cobalt mine in the world is in operation in Morocco.

This means the fortunes of cobalt – now driven by battery demand – is still at the mercy of nickel and copper commodities which is driven by industrial demand. This is causing long term planning issues for the EV supply chain.

Cobalt used in lithium ion batteries equated to 48,000 tonnes in 2016 but this is set to increase to 180,000 tpa by 2025. While opportunities for producers' external to DRC are available, the sheer volume of new supply needed by the market means there will be no EV industry without DRC cobalt.

Most of refining to a battery grade cobalt chemical will occur in China.

Nickel – a raw material associated with cobalt but also mined individually – is growing in importance for a lithium ion battery consumer. The trend of using more nickel in a cathode and less cobalt is one that is just beginning in the commercial lithium ion space.

For NMC formulations – a chemistry that will be the number one format in the EV and utility storage space - the industry has traditionally used a 1:1:1 formula – 1-part nickel, 1-part manganese and 1-part cobalt.

However, 5:2:3, 6:2:2 and 8:1:1 nickel-rich formulations are now being introduced into lithium ion battery production lines around the world.

This is a move that will see battery grade nickel demand grow from 75,000 tpa in 2016 to anywhere between 300-400,000 tpa by 2025 depending on which chemistries take hold.

While nickel metal is a commodity that is produced in the millions of tonnes a year, the battery grade chemical material is specialist with only a handful of major producers outside of China including Japan’s Sumitomo Metals Mining, which operates mines and processing plants, and Belgium’s Umicore. However, the vast majority of battery grade nickel sulphate is produced in China.

Interest in the market has seen major nickel miners such as Vale, BHP Billiton, and Rio Tinto seek to enter the battery grade space. However, not all nickel deposits can produce a commercially viable battery grade material. High and lower grade class 1 nickel deposits are the most suitable yet the most capital intensive to move into production.

Competing technologies to lithium ion

Vanadium flow:

For stationary storage applications, vanadium flow batteries have been the most talked about as best-in-class for this application due to its lifetime versus lithium ion.

The challenge for this market is finding a champion for the technology with only a handful of producers competing for market share. The upfront cost of the technology is more expensive than lithium ion and despite offering a longer life time, this is discouraging some buyers.

Vanadium flow is heavily reliant on vanadium raw material that is processed into vanadium pentoxide form. Vanadium raw material output totalled 72,000 tonnes in 2016 however vanadium pentoxide used in batteries was under 3% of this demand.

Manufacturers of vanadium flow batteries will likely need to control own their own raw material source to minimise the raw material supply and price fluctuation risk which can be very disruptive to the adoption of this technology. A major positive of this technology is that vanadium can be recycled and some producers are looking at raw material leasing options for financing new battery installations.

Solid state:

Solid state batteries are the most promising successor to lithium ion but a technology that is still many years for widespread commercial adoption.

Compared to a lithium ion battery, there are no liquid components to solid state and it uses a lithium metal or silicon anode. The gains in changing the anode are the main theoretical benefits over a lithium ion battery and include higher energy density and faster charging.

Solid state technology in the commercial world has seen some activity in mid-2017. UK-based Dyson revealed it aims to enter the EV market using solid state by 2020. This was made possible because of its 2015 acquisition of Sakti 3, a US-based solid-state technology developer.

A second most recent boost was from Porsche’s confirmation that it will also seek to use solid state batteries in 911 and Boxster in post-2020 production models.

Wide scale solid state battery adoption is far from guaranteed and it is yet to be seen whether solid state can work safely in real world scenarios. But the technology is widely tipped as the successor to lithium ion in a post 2030 world.

2025 Vision: Lithium ion here to stay, supply chains need to evolve

While there are huge opportunities with the energy storage revolution there are also huge risks.

The demands EV manufacturers are placing on raw material miners to chemical processors and cathode manufacturers are huge – they are being asked to increase their business footprint by 5-10 times in a 7-year period.

At present, there is little desire to share this capital and commercial risk of building new mines or expanding their business to meet this new demand.

Major auto manufacturers will eventually have to conclude that supply chain partnerships and capital investment is the only way to secure lithium, graphite, cobalt, nickel or lithium ion battery cells. But this decision-making process is slow for players outside of China and risks derailing any form of revolution in the energy storage industry.

Market momentum is now with lithium ion batteries and for this first phase of the energy storage revolution the choice has been made, certainly for EV. Over $35bn has been committed to expanding lithium ion battery plants while the lithium industry has raised $1bn to build new supply.

This investment is short by some way.

The investment into lithium ion battery capacity needs to be four times larger to satisfy demand for the mid-2020s and it needs to be 10 times larger to create a new blueprint for a post-2030 world. The lithium industry, as an example, will need raised between $7-10bn to keep pace with this new capacity and demand for EVs.

The US is very active on EV innovation mainly owing to activities by Silicon Valley based companies like Tesla and Proterra. US involvement in the raw material to cathodes to battery cell links in the supply chain is very limited however with the sway of industrial power lying in Asia Pacific countries most notably China, Japan and Korea.

This energy storage revolution is global and unstoppable. For countries and corporations, positioning themselves accordingly to take advantage of this should be of paramount importance and longer term (~10 year) decisions need to be made.

Where we stand today in 2017, China is not only at the centre of mass market EV development and deployment but also of cathode production, battery grade raw material refining, and the building out of new battery cell capacity.

Those that control raw material and chemical / cathode refining knowhow and capacity will control the lithium ion battery supply chain. And those that control the lithium ion battery supply chain will be the biggest influencers on the next generation auto and energy industries.

Simon Moores
Managing Director
Benchmark Mineral Intelligence
UK