“LIB raw material supply chain bottlenecks: looking beyond supply/demand/price”

Robert Baylis
Managing Director
Outline

1. Context

2. Current global LIB commodity environment

3. Risks

4. Examples of supply chain issues:
   1. Nickel
   2. Lithium
   3. Cobalt

5. Conclusion & strategy
Context

“Raw materials are becoming more important to consumers”
Batteries are becoming a more costly part of the average automobile build, meaning battery cost is becoming paramount for economics.

**Current premium EV offering**
- **2016 Tesla Model S 100kWh, 315 mile range**
  - Sticker price: US$134,500 (before credits)
  - Margin: 23% (approx)
  - Cost: US$109,350
  - Pack price: US$26,000 (US$260/kWh)
  - Cell price: US$19,000 (US$190/kWh)
  - Cell: 8,256 no. Panasonic 18650 cells
  - Chemistry: Li-NCA-C (+/- Si)

**Current standard EV offering**
- **2016 Chevy Bolt 60kWh, 238 mile range**
  - Sticker price: US$37,500 (before credits)
  - Margin: 10% (assumed)
  - Cost: US$34,090
  - Pack price: US$12,000 (US$200/kWh)
  - Cell price: US$8,700 (US$145/kWh)
  - Cell: 288 no. LG pouch cells
  - Chemistry: Li-NMC-C

**Target US$150/kWh?**
- **2016 Avg. car 100kWh (>315 mile range)**
  - Sticker price: US$33,560 (no credit)
  - Margin: 10% (target)
  - Cost: US$30,500
  - Pack price: US$15,000 (US$150/kWh)
  - Cell price: US$12,000 (US$120/kWh)
  - Cell: TBC
  - Chemistry: TBC

Source: Roskill
Picture credit: Tesla and GM
Material costs are not predicted to fall as quickly as pack and cell manufacturing, therefore representing a higher share by 2025

- Cell, but particularly pack, manufacturing costs are forecast to fall because of scale and maturity of assets (less R&D, depreciation etc.)

- Material costs have more limited scope to fall, as much of the cost is in their constituent raw materials

**LIB cost breakdown (US$/kWh)**

- Assumptions for US$150/kWh pack price:
  - 10% reduction in material unit cost
  - 30% reduction in cell manufacturing
  - 40% reduction in pack manufacturing

- Material share of cost in 2025:
  - Cathode 14%
  - Anode 6%
  - Electrolyte 6%
  - Separator 10%
  - Collectors 7%
  - Other 5%

Source: Roskill
LIBs are raw material intensive products; “mined” materials account for 24% of total pack manufacturing costs

- Almost all cell materials are derived from mined or oil-based products, with the cathode, anode, collectors and cell hardware (casings) of metal/minerals or oil derivatives.

- Packs and modules are also raw material intensive, with hardware and electrical/electronics also key users, especially of copper.

**Material use by LIB component**

<table>
<thead>
<tr>
<th>Material Component</th>
<th>Aluminum</th>
<th>Cobalt</th>
<th>Copper</th>
<th>Graphite</th>
<th>Lithium</th>
<th>Manganese</th>
<th>Nickel</th>
<th>Other Non-ferrous</th>
<th>Ferrous</th>
<th>Chemical &amp; Plastic</th>
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<tbody>
<tr>
<td>Active Cathode Material</td>
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<td>Cell Hardware</td>
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<td>Module / Pack Hardware</td>
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Source: Roskill
Of the US$7.1Bn spent on LIB components in 2015, separator, electrolyte, copper, aluminium and cobalt were the major contributors.

Source: Roskill

Note: Lithium in metal equivalent, not LCE
LIB raw material status

“large impact seen to most LIB raw materials through 2025”
LIB output expected to more than triple by 2025 + upside potential, meaning more raw material needed (nb. cathode mix dependent)

Assumptions:

- LIB:
  - 360% increase in base-case (223GWh)
  - 260% increase in low-case (161GWh)
  - 500% increase in high-case (312GWh)

- Cathode share in 2025 (base-case):

Source: Roskill estimates

Note: Graphite is crude form, before losses to produce battery-grade
LIB growth will transform the dynamics of some raw material markets with increases in market share for this use.

Share of the LIB market per commodity in 2015:

- Lithium, 66kt LCE, 38%
- Cobalt, 35kt, 39%
- Manganese, 11kt, <1% (even when excl. ferroalloy use)
- Nickel, 16kt, <1%
- Graphite, 96kt, 4%

Most significant changes expected to 2025:

- Lithium: 38-57%
- Cobalt: 39-50%
- Graphite: 4%-8%
- Nickel: 1-3%
- Manganese: <1%-2%

Source: Roskill data

Note: Manganese other excludes FeMn and SiMn use in steel
Risk to consumers

"the current situation could be considered unsustainable"
LIB raw material prices are at decade lows in nominal terms, and century lows when adjusted for inflation = good time to be a consumer

Notable price spikes include:

- Cobalt in 1977-79 – civil war in the DRC
- Nickel in 2003-08 – China-fuelled commodity supercycle
- Lithium in 2005-08 – re-emergence of high-cost mineral conversion after brine dominated early 2000s
- Graphite in 2008-11 – shortage of large flake for refractories from China
- Lithium in 2016 – increased corporate control of raw material flow, supply growth lagging demand

Why worry about prices?

Source: Roskill; LME; USGS
The mine-to-market added value process is long, and has outside influences, presenting potential pinchpoints/bottlenecks.

Source: Roskill

Need to determine where the bottlenecks are.
Integration is limited, reflecting expertise and previous commoditization of products at various stages; bottlenecks are possible at all levels

- Li-ion battery manufacture is a multi-stage business
- The final product incorporates a range of elements which mostly require different business expertise and knowledge base
- Companies occupying each segment of the industry are not the same, though some larger companies are integrated, both horizontally and vertically

Examples:
- Auto-LIB: Lithium Energy Japan (GS Yuasa & Mitsubishi) Automotive Energy Supply Company (NEC & Nissan), Gigafactory (Panasonic & Tesla), BYD
- LIB-Cathode/Anode: Some internal capability
- Cathode/anode-raw materials: Umicore, SMM, BTR, Pulead, Shanshan (all leading producers)

Source: Roskill
Material nuances

“competition for resources, feedstock availability, price movement are all commodity dependent”
LIB has **competition with other uses** for supply of nickel, that are currently much larger and more valuable to producers.

- The focus of the nickel market is on stainless and other special steels, which use nickel metal and ferronickel/NPI.
- Prices dictated by the steel industry and overall mine/refined supply.

**Output of nickel products, 2015**

- Ni cathode: 40%
- NPI: 21%
- FeNi: 18%
- Other electrolytic metal: 6%
- Powder and briquettes: 5%
- Ni sulphate: 3%
- Other <1%
- Utility, oxide sinter, compacts and rondelles: 7%
The link between the price of the “commodity” and LIB product does not always track one-to-one.

• The premium paid for nickel sulphate in the Chinese market, compared to the price paid for nickel cathode, has increased to about 30%, up from around 15% in previous years.

Source: Asian Metal, Roskill
Increased **control of feedstock**, and later refined product, shipment has led to a virtual tightness in lithium supply.

- Talison (Tianqi 51% / Albemarle 49%) controls majority of supply of feedstock to China converters.
- Talison’s shareholders have been consuming (Tianqi internally) and tolling (Albemarle) more feedstock in 2016.
- **Converted minerals output, 2016E**
  - Tianqi 43%
  - Talison 31%
  - SQM 22%
  - FMC 9%
  - China brine 2%
  - China mineral 5%
  - Neometals/MRI/Ganfeng 1%
  - Orocobre 5%
  - Galaxy Resources 3%
  - General Lithium 9%

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  - Orocobre 5%
  - Galaxy Resources 3%
  - General Lithium 9%
  - Technical minerals 8%

- Ex-Tianqi, these converters held 21% of refined lithium product output in 2016.
- But, they are major suppliers of battery-grade product: carbonate domestically and hydroxide export.

- In 2017, Ganfeng will start sourcing from its JV operation Mt Marion.
- Other converters have off-take with Galaxy (now shipping) and Pilbara (under construction).

Source: Roskill
The cobalt price has several drivers, but **doesn’t always react to market fundamentals** due to large physical trading business.

- Through-put of nickel at sulphide and laterite smelter-refineries
- Flow of concentrates and intermediates from the DRC to China
- Through-put of copper at refineries, and status of cobalt extraction circuits largely in the DRC
- Balance of demand for cobalt metal and chemicals (each can be converted into the other)

**Share of cobalt supply by stage (%)**
- DRC
- China

**Cobalt chemical supply/demand balance (kt)**
- **2013, 2014, 2015, 2016e**
  - Chemical supply
  - Chemical demand

**Metal supply/demand balance (kt)**
- **2013, 2014, 2015, 2016e**
  - Metal supply
  - Metal demand

Source: Roskill
Conclusion

“the raw materials industry may be a drag to LIB growth”
The raw materials (mining) industry is slow to adapt to change and often mistimes the wave, hence its boom/bust cycles

<table>
<thead>
<tr>
<th><strong>LIB-side changes</strong></th>
<th><strong>Raw material supply-side changes</strong></th>
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</thead>
<tbody>
<tr>
<td>• Switch to high-Ni chemistries = greater nickel and lithium hydroxide requirement</td>
<td>• Low nickel prices = closure of sulphide nickel mines and lower smelting/refining, impact on nickel volumes</td>
</tr>
<tr>
<td>• Switch to high-Ni chemistries = cobalt and manganese become more important as additives than stand-alone</td>
<td>• Low nickel prices = reduction in cobalt by-product from nickel smelters</td>
</tr>
<tr>
<td>• LFP for XEV and ESS = more iron-phosphate</td>
<td>• M&amp;A activity likely to increase = fewer suppliers</td>
</tr>
<tr>
<td>• Sol-gel LFP = greater lithium hydroxide requirement</td>
<td>• Low prices = challenging for project developers wanting to bring new supply onstream</td>
</tr>
<tr>
<td>• End of smartphone/tablet surge and lower-Co LIBs = less cobalt growth for LCO</td>
<td>• Shift from metal-focus to chemical-focus as oxides and salts increasingly required</td>
</tr>
<tr>
<td>• Unlikely any change from graphite for anode in short-term</td>
<td>• Mining industry is large and slow to react</td>
</tr>
<tr>
<td>• Increased performance = anode additives (Li, Sn), alloys and nano materials</td>
<td>• Consumers more aware as news publicised</td>
</tr>
</tbody>
</table>

Roskill

Approachable • Independent • Expert
How to de-risk raw material supply and price? Different options for influence by final consumer

Reliance on supply chain
- Battery materials producers’ own secure supply arrangements

Integrated upstream producer option.
- Integrated supply or secure offtake
- Cobalt oxide Nickel sulphate

Refined producer of required feedstock.
- Refined feedstock
- Integrated
  - Direct link if battery material producer has Ni sulphate/Co oxide facilities, or can build those

Mine producer off-take
- Mine feedstock
  - Integrated refined production

Complete integration
- Mine feedstock
  - Battery material producers

Specify sourcing “best practices”
The automotive industry is waking up to raw material issues, but based on short-term growth projections it maybe too late to prevent an impact

- **Mid-2000s to early-2010s commodity super-cycle largely China and western debt fuelled. Fall-out (debt crisis, China slowdown, overcapacity) well underway and possibly has hit the bottom for key LIB raw materials.**

- **End-2015 into 2016 price jump for lithium first impact of surging LIB market impact on raw materials (albeit some producer influence).**

- **Does anyone remember the impact of cobalt prices on LIB market in 2007/08... only a reduction in cobalt-intensity (emergence of NMC) has prevented larger impact on LIB industry in mid-2010s. Emergence of high-Mn NMC similar fall-back for nickel?**

- **Cobalt looks at risk again, as contentious DRC election looms in late 2016 and nickel-based output continues to decline (albeit mainly for metal, this is the key price benchmark).**

- **It may not be possible to reduce raw material costs much further without chemistry changes, but raw material costs could have negative impact on costs through price fluctuation.**

- **Is backward integration a path forward for LIB/auto manufacturers? Unlikely, but closer ties possible.**
Thank you.
Any questions?
Roskill provides almost full-spectrum research coverage of LIB “mined” material markets, and bespoke work to help clients understand them.

<table>
<thead>
<tr>
<th>Independent. Approachable. Expert</th>
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<tbody>
<tr>
<td>Established in 1930s, concentration on niche mineral and metal markets since the 1970s</td>
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<thead>
<tr>
<th>Consulting activities:</th>
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<tbody>
<tr>
<td>Market assessments</td>
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<tr>
<td>Feasibility studies</td>
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<tr>
<td>Industry analyses</td>
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<tr>
<td>Acquisition studies</td>
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<tr>
<td>Strategic planning</td>
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<td>Competitive evaluation studies</td>
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<td>Commercial intelligence</td>
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<td>Due diligence</td>
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<table>
<thead>
<tr>
<th>Research coverage:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cathode:</td>
</tr>
<tr>
<td>• Lithium, cobalt, nickel, manganese</td>
</tr>
<tr>
<td>• Anode:</td>
</tr>
<tr>
<td>• Graphite (natural AND synthetic), hard and soft carbon, silicon, tin, lithium</td>
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<tr>
<td>• Electrolyte:</td>
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<tr>
<td>• Lithium, fluorspar and fluorochemicals</td>
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<tr>
<td>• Collectors:</td>
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<tr>
<td>• Copper and aluminium</td>
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<tr>
<td>• Industry reports:</td>
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<tr>
<td>• Lithium-ion batteries, vanadium redox batteries</td>
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<tr>
<td>• Other related research:</td>
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<tr>
<td>• Vanadium; rare earths</td>
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