The EV Revolution:
Impacts on critical raw material supply chains

David Merriman
Manager, Battery & Electric Vehicle Materials Division
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Key points to determine...

What is criticality?  
What materials are used?

Source: Roskill
What is criticality?
• Criticality is not real, it’s a concept of importance by the consumer (or study group…)
• There are many viewpoints to consider; criticality is specific to:
  - End-use application
  - Regions
  - Company

Source: Roskill
What materials are used?

• There are a large range of materials used in EVs, including:

  EV Batteries

  - Lithium
  - Cobalt
  - Manganese
  - Nickel
  - Iron
  - Carbon

  Cathode materials
  Anode materials
  Electrolyte
  Foils

  Chassis alloys / Light-weighting

  - Iron
  - Aluminum
  - Molybdenum
  - Magnesium
  - Carbon
  - Nb

  Focus on 3 main markets:

  - Lithium
  - Cobalt
  - Rare Earths

  Adversely affected

  - Tungsten
  - Platinum

  Positively affected

  - Soda Ash
  - Fluorine

  Cabling

  - Cables & connectors
  - Charging infrastructure
  - Electronics

  Electric Motors

  - Permanent magnet motors
  - Glass pigmentation
  - LCD screens

  Source: Roskill
Lithium supply chain

Miners & Briners

Mineral

Concentration

Conversion

Lithium compounds

Purification

Mineral Concentrate

Anode precursor

Cathode precursor

Electrolyte material

Anode Material

Cathode Material

Electrolyte Material

Battery cell

Processors

Specialist Battery materials manufacturers

Roskill
Rechargeable batteries represented >50% demand in 2018

Lithium demand by end-use, 2005-2018

Source: Roskill
Lithium-ion battery: Changing battery demands

• Portable electronics dominant ~90%
• Automotive in its infancy
• ESS yet to emerge

2010

• Automotive applications dominant
• Portable electronics remain significant ~25%
• ESS represents 1% of MWh total

2018

• Automotive applications form almost entire market
• ESS and Power & motive represent ~3%
• Portable electronics <5%

2025

Source: Roskill
Automotive: xEV sales to exceed ICEs by 2029

- xEV sales have grown by 26%py since 2010, compared to 3% py in total vehicle sales (ICE + xEV)
- xEVs share will exceed ICE cars share by 2029. But ICE sales will be peaking next year in 2020 (no further growth)
- Sales in 2018 reported xEVs to total 5.38M units. Market penetration in 2018 was ~5.5% of xEVs
- Roskill’s Automotive & Battery Materials model forecasts growth in xEV sales of 29%py to 2025
- Total vehicle sales to grow by 1.7%py over same period
- xEVs market penetration to reach 29% in 2025 and >50% in 2029

Source: Roskill
How has the dominance of xEVs changed the lithium supply chain?
Cathode material requirements have shifted

- Greater energy density, power and safety requirements in automotive applications has caused a shift in cathode materials
- LCO and LMO not suitable for automotive use, firstly the use of LFP (China) and then NMC and NCA cathodes
- Changing raw material demands in rapidly growing market

Lithium Cobalt Oxide (LCO)
Lithium Manganese Oxide (LMO)
Lithium Iron Phosphate (LFP)
Lithium Nickel Cobalt Manganese oxide (NMC)
Lithium Nickel Cobalt Aluminium oxide (NCA)

Source: Roskill
Higher energy-density materials favoured

- LMO and LFP used in first generation EVs, though short-life and lower energy density were unfavourable.

- Higher-nickel NMC providing energy density (vehicle range) have been favoured, supported by subsidies for EVs with longer ranges and consumers ‘range anxiety’

- Shift to NMC 532 → NMC 622 → NMC 811

- Higher Ni cathodes require specific raw materials, manufacturing conditions and management systems
LiOH required for the transition to High-Ni NMC & NCA

- Lithium carbonate used historically because of price and availability. Largely used in production of LCO, NMC 111 and LMO.

- Higher-nickel cathode materials (NCA, NMC 622 and NMC 811) require LiOH. Other cathode chemistries (LFP, NMC 532) may used either carbonate or hydroxide.

- New production capacity targeting LiOH output, representing 75% of new/expanded capacity in pipeline.

Cathode usage by type, (% market share) 2015-2025
Lithium: Further expansions and new production required

- Planned expansions at new producers
- Set-back and delays at new producers and expansion may widen the ‘gulf of opportunity’ for new producers
- Deficit exceeding 100kt LCE by 2023 forecast, though capacity sufficient to meet demand until 2028
- Further capacity expansions are expected at major processors
- Over 100kt additional lithium production required each year to meet demand growth
- Significant investment in expansions and new producers required

Refined lithium supply-demand balance (t LCE)

Source: Roskill
Demand to increase multiple times in batteries

Li and Ni demand in batteries, 2018-2025 (Indexed 2018)

- **Lithium** demand to increase 6x by 2025, with little opportunity for substitution
- **Nickel** intensity of use increasing accelerating demand growth over 4x
- **Cobalt** being designed out, though demand forecast to over 2x in years to 2025

Source: Roskill
Choice of cathode impacts raw material demand

Material composition of major types of cathode (% of weight)

- NCA 3% Co
- NCA 9% Co
- NCM 811
- NCM 622
- NCM 523
- NCM 111
- LMO
- LFP

Source: Roskill
Cobalt intensity of use decreases, though demand increases

Co demand in batteries by end-use, 2018-2028 (t Co)
Cobalt sources are largely by-products of Cu and Ni

Source: Roskill
OEMs are starting to lock in supply but risk appetites vary

Selected deals to procure cobalt, 2017 & 2018

<table>
<thead>
<tr>
<th>Year</th>
<th>Buyer</th>
<th>Buyer type</th>
<th>Country</th>
<th>Source</th>
<th>Source type</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>Easpring Material Tech</td>
<td>Cathode manufacturer</td>
<td>China</td>
<td>Clean Teq</td>
<td>Project</td>
<td>Australia</td>
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<tr>
<td>2018</td>
<td>POSCO</td>
<td>Cathode manufacturer</td>
<td>Korea</td>
<td>Huayou Cobalt</td>
<td>Producer</td>
<td>DRC/China</td>
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<tr>
<td>2018</td>
<td>GEM</td>
<td>Battery recycler</td>
<td>China</td>
<td>Glencore</td>
<td>Producer</td>
<td>DRC/other</td>
</tr>
<tr>
<td>2018</td>
<td>LG Chem</td>
<td>Battery maker</td>
<td>Korea</td>
<td>Huayou Cobalt</td>
<td>Producer</td>
<td>DRC/China</td>
</tr>
<tr>
<td>2018</td>
<td>SK Innovation</td>
<td>Battery maker</td>
<td>Korea</td>
<td>Australian Mines</td>
<td>Project</td>
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<tr>
<td>2018</td>
<td>LG Chem</td>
<td>Battery maker</td>
<td>Korea</td>
<td>Cobalt Blue</td>
<td>Project</td>
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<tr>
<td>2018</td>
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<td>Cathode manufacturer</td>
<td>China</td>
<td>Pacific Rim Cobalt</td>
<td>Project</td>
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<tr>
<td>2019</td>
<td>BWM</td>
<td>OEM</td>
<td>Europe</td>
<td>CTT &amp; Glencore</td>
<td>Producer</td>
<td>Morocco &amp; Australia</td>
</tr>
</tbody>
</table>

Source: Roskill
Rare Earths – Electric motors

Permanent magnet motors

- Nd-(Pr-Dy)-Fe-B
- Sm-Co
- Ferrite

Induction motors

- Electromagnets

Source: General Motors, Roskill
Electric vehicles – *Without a motor its just an energy storage system*

- **Permanent magnet** synchronous motors (PMSM) are the motor of choice in electric vehicle drivetrains (> 90%).
- Currently, leading power-density permanent magnets are rare earth **neodymium-iron-boron** (NdFeB).
- New motor/generator technologies are **optimising the distribution of magnets** in size-specific designs.

### Comparison of motor efficiency

![Energy conversion efficiency vs RPM](chart)

### Choice of motor technology in NEVs

![Automotive segments](chart)

*Source: Roskill*
Electric vehicles set to reshape the NdFeB (and REE) market

- **Drivetrain motors** require higher quality and larger permanent magnets compared to traditional applications.
- Pure battery EVs and LSEVs use more permanent magnets per motor than HEVs (Toyota Prius: 1.5kg NdFeB)

### NdFeB demand by NEV type

**2018e**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2019f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2020f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2021f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2022f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2023f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2024f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2025f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2026f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2027f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2028f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

**2029f**
- HEV: 31%
- PHEV: 14%
- Other auto and vehicle: 29%

*Source: Roskill*
Reaction: Greater disparity in REE demand by element

- Visualising the relative performance of a suite of 15 elements in a rare earth world defined by neodymium.

Source: Roskill
Reaction: China reinforcing domestic NdFeB supply chain

- Chinese companies have significantly increased production capacity for NdFeB alloy and magnet production in 2018, creating latent capacity

- Despite this, companies such as Leexia Tungsten (Xiamen Tungsten), Yantai Zhenghai Magnets, Cixi Gongli Magnetic Industry and Tianjin Sheng Magnetic One all constructing new capacity

- Requirements for Nd, Pr and Dy increasing:
  - Domestic production
  - Rest of world producers
  - Recycling of magnet materials

- Opportunity of for ROW producers, though reluctance for Chinese involvement, little financing opportunities, processing knowledge and develop supply chains outside China

Source: Roskill
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