Why investigate battery materials??

• Some expect the share of electricity as motive power for transportation to increase as more electric vehicles (EVs) and plug-in hybrid EVs (PHEVs) are sold. Batteries also may provide storage for grid and off-grid power.
• Currently, preferred transport battery chemistry is Li-ion as the main cathode component with cobalt (Co) added for safety. Anodes are typically graphite. Li-ion batteries (LIBs) already dominate consumer electronics.
• LIBs are expected to maintain their dominance in the EV sector because of their relatively high ratings in energy storage and dispatch, cost, life span and performance under various ambient conditions.
• What are the global resources and reserves for Li and Co? With what mine-design production capacities?
• Are there any logistical, legal, and/or regulatory constraints to timely and cost-efficient development and delivery of these resources?

Battery Materials Supply Chains*

*A full working paper is forthcoming fall 2015.
**Production costs are projections for new projects and include capital costs. Older projects which have paid back capex will have lower costs which only reflect opex.

Materials Extraction
• Lithium has traditionally been mined from two types of sources:
  • hard rock pegmatite, and
  • brine from continental salt lakes.
• Australia, China, Canada, Brazil, and the US have the major known pegmatite resources.
• Brine sources are mainly in Bolivia, Chile, Argentina. Significant resources also are present in China, US.
• The US also has oil field brines, hectorite clays and geothermal brines.
• Bolivia, the largest resource owner, has not yet started commercial production.
• Bolivia, Chile, Argentina collectively hold almost 58% of the world’s Li resources.
• Chile, Australia are the leading producers and exporters of Li.
• Chile alone holds more than 55% of the world’s reserves (almost all of Chile’s resources are counted as reserves because of the low cost of production in Salar de Atacama).
• Co is mainly extracted with copper (Cu) and nickel (Ni). The Democratic Republic of Congo (DRC) is the largest Co producer. China is the largest producer of refined Co (from imported DRC ore).

<table>
<thead>
<tr>
<th>USGS Data</th>
<th>2014 Production (metric tons)</th>
<th>2014 Production cost ($/ton LCE)**</th>
<th>Resources (metric tons)</th>
<th>Resources % of world</th>
<th>Reserves (metric tons)</th>
<th>Reserves % of world</th>
<th>Resource % Brine</th>
<th>Resource % Pegmatite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolivia</td>
<td>0</td>
<td>&gt;1,500 - 1,750</td>
<td>9,000,000</td>
<td>22.6%</td>
<td>n/a</td>
<td>0.0%</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Chile</td>
<td>12,900</td>
<td>1,500</td>
<td>7,500,000</td>
<td>18.9%</td>
<td>7,500,000</td>
<td>55.5%</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Argentina</td>
<td>2,900</td>
<td>1,876 – 2,000</td>
<td>6,500,000</td>
<td>16.3%</td>
<td>850,000</td>
<td>6.3%</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>USA</td>
<td>870</td>
<td>3,291</td>
<td>5,500,000</td>
<td>13.8%</td>
<td>38,000</td>
<td>0.3%</td>
<td>1%</td>
<td>47%</td>
</tr>
<tr>
<td>China</td>
<td>5,000</td>
<td>n/a</td>
<td>5,400,000</td>
<td>13.6%</td>
<td>3,500,000</td>
<td>25.9%</td>
<td>77%</td>
<td>23%</td>
</tr>
<tr>
<td>Australia</td>
<td>13,000</td>
<td>1,476</td>
<td>1,700,000</td>
<td>4.3%</td>
<td>1,500,000</td>
<td>11.1%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Canada</td>
<td>0</td>
<td>3,277</td>
<td>1,000,000</td>
<td>2.5%</td>
<td>n/a</td>
<td>0.0%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>DRC</td>
<td>0</td>
<td>n/a</td>
<td>1,000,000</td>
<td>2.5%</td>
<td>n/a</td>
<td>0.0%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Russia</td>
<td>0</td>
<td>n/a</td>
<td>1,000,000</td>
<td>2.5%</td>
<td>n/a</td>
<td>0.0%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Serbia</td>
<td>0</td>
<td>n/a</td>
<td>1,000,000</td>
<td>2.5%</td>
<td>n/a</td>
<td>0.0%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Brazil</td>
<td>400</td>
<td>n/a</td>
<td>180,000</td>
<td>0.5%</td>
<td>48,000</td>
<td>0.4%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>1,000</td>
<td>n/a</td>
<td>n/a</td>
<td>0.0%</td>
<td>23,000</td>
<td>0.2%</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Portugal</td>
<td>570</td>
<td>n/a</td>
<td>n/a</td>
<td>0.0%</td>
<td>60,000</td>
<td>0.4%</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Total</td>
<td>36,640</td>
<td>39,780,000</td>
<td>100%</td>
<td>13,519,000</td>
<td>100%</td>
<td>68%</td>
<td>24%</td>
<td></td>
</tr>
</tbody>
</table>
Lithium Flow Diagram: Sources to End Uses 2014 & Base Case 2025 Forecast (metric tons)*

- Continental brine is the larger (and cheaper) source of Li.
- Lithium carbonate ($\text{Li}_2\text{CO}_3$) is the largest produced lithium compound.
- Lithium hydroxide and lithium chloride are derived from $\text{Li}_2\text{CO}_3$.
- $\text{Li}_2\text{CO}_3$ is extracted from both pegmatite and brine sources.
- Concentrates are used almost exclusively by the ceramics and glass industry.

*See following slide for discussion/explanation. All figures in metric tons of contained lithium.

Data source for calculations and uses:
- US Geological Survey, Albermarle, FMC
**2025 Base Case Demand Forecast**

- Batteries are expected to drive most of Li demand growth in the future (see Base Case Demand Forecast on right).
- In 2025, EV batteries might account for 65% and consumer electronics for 35% of total LIB production (Deutsche Bank, 2011).
- Such growth could put stress on both pegmatite and brine resources.

### Lithium Demand Projection: Base Case*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Li Content (Metric tons)</td>
<td>10,000</td>
<td>20,000</td>
<td>30,000</td>
<td>40,000</td>
<td>50,000</td>
<td>60,000</td>
<td>70,000</td>
<td>80,000</td>
<td>90,000</td>
<td>100,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**In 2020...**

At the current average utilization of lithium production capacity of 55% (yellow line on bars):

- The projected capacity from continental brine and pegmatite sources alone (orange bar) falls short of both base/high Li demand scenarios.
- If hectorite projects materialize as announced (dark blue bar), both low and base demand scenarios for Li can be fulfilled.
- If all new projects come online including those from geothermal brine and oil field brine (brown bar), all demand scenarios can be met.

At the current average utilization of cobalt production capacity of 58% (yellow line on bar):

- Production will fall short of demand in almost all three demand scenarios in 2017.
- A 75% utilization should suffice in 2017 to meet even the high demand for Co; but new capacity needed in the high demand case before 2020 (upper extent of light blue bar).

Risks: access to lithium resources (e.g., Bolivia); legal/regulatory changes (e.g., Chilean government’s desire to create a new state mining company); environmental concerns resulting from the scaling up of mining activity.

---

* Growth rates of Li end uses for base case demand forecast: batteries 15%, ceramics and glass 4%, lubricating greases 5%, for continuous casting 3%, air treatment 3%, for polymer production 4%, other uses 4%, and -20% for aluminum. ** One ton of lithium = 5.31 tons LCE