Battery Materials Supply Chains*

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?

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

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).

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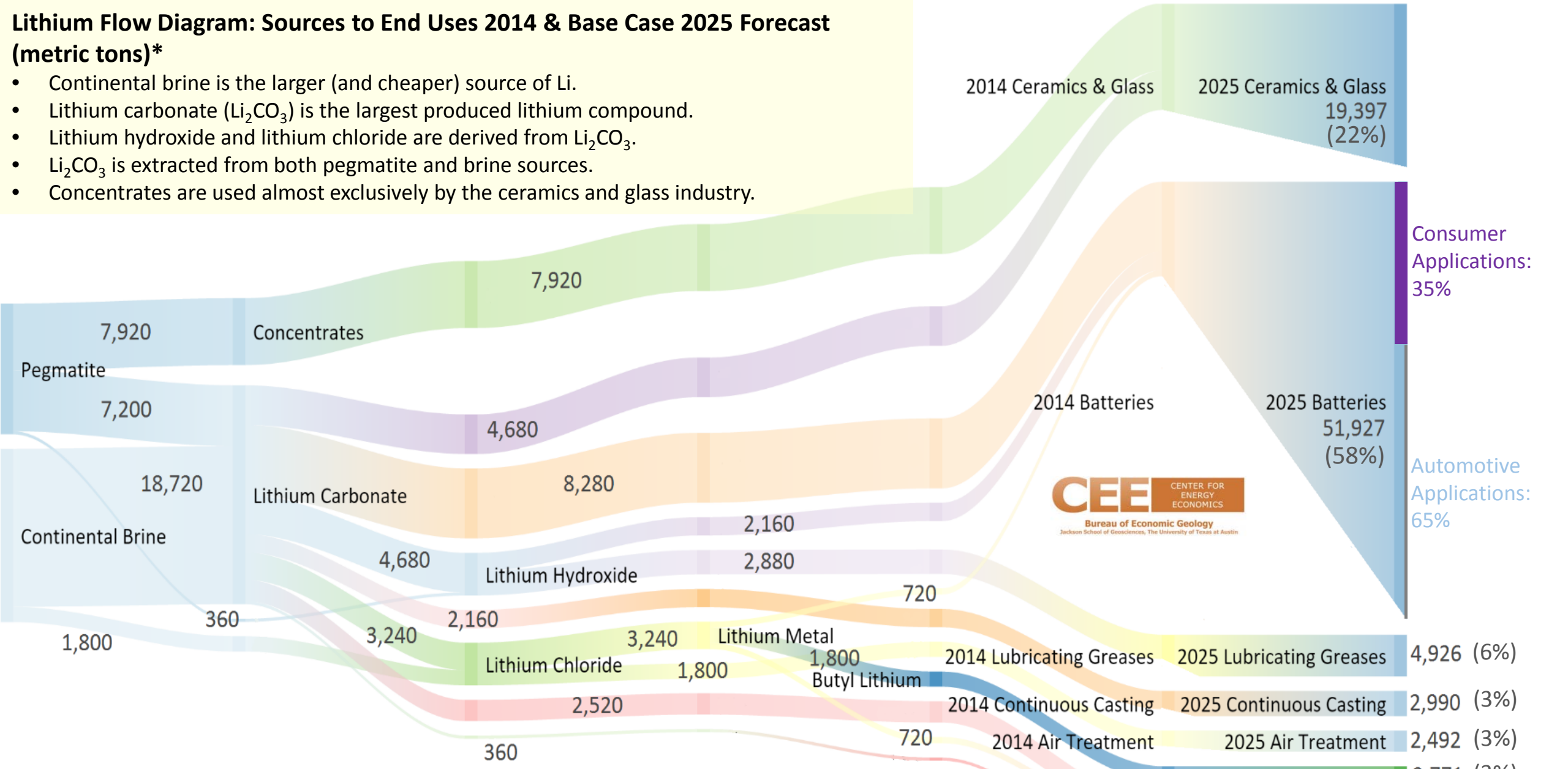
***A full working paper is forthcoming fall 2015.**

**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.

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 (Li_2CO_3) is the largest produced lithium compound.
- Lithium hydroxide and lithium chloride are derived from Li_2CO_3.
- Li_2CO_3 is extracted from both pegmatite and brine sources.
- Concentrates are used almost exclusively by the ceramics and glass industry.



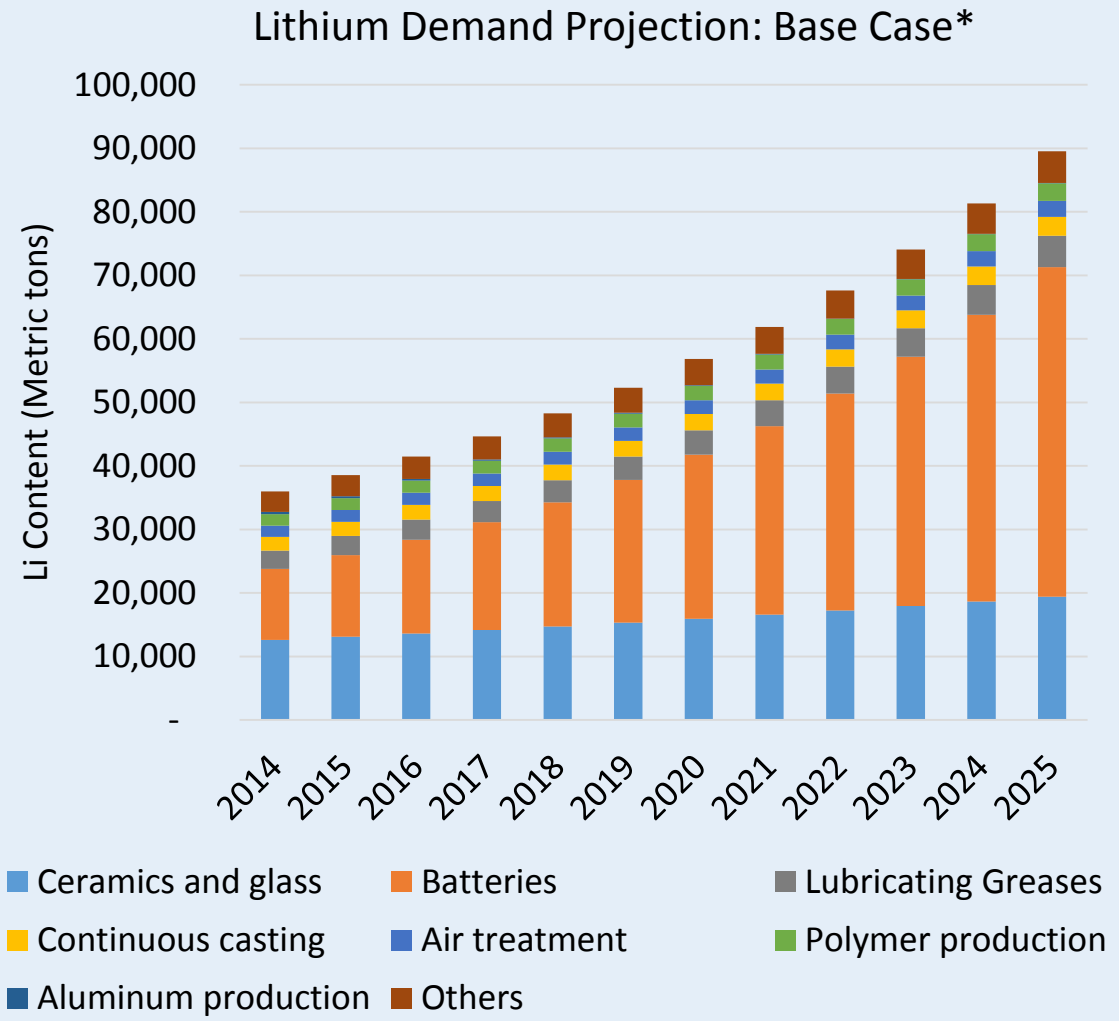
*See following slide for discussion/explanation. All figures in metric tons of contained lithium.

Data source for calculations and uses:

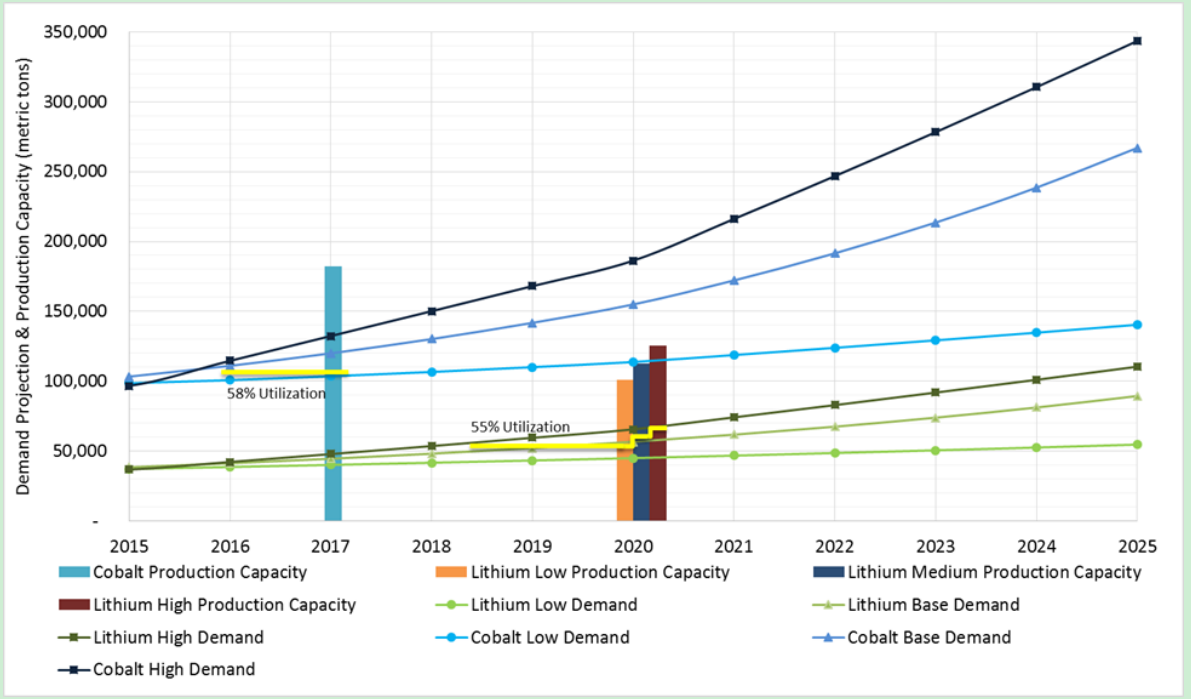
- US Geological Survey, Albermarle, FMC
- Evans (2014), Peiro (2013), Yaksik (2009), Deutsche Bank (2011)

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.



Capacity versus Demand Projections



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.

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* 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