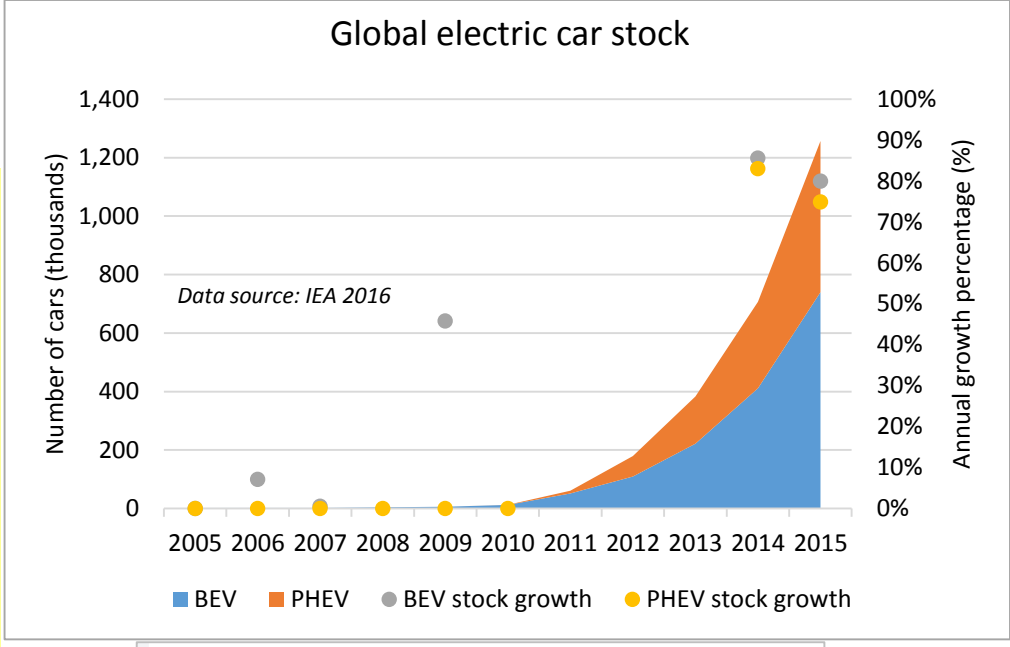
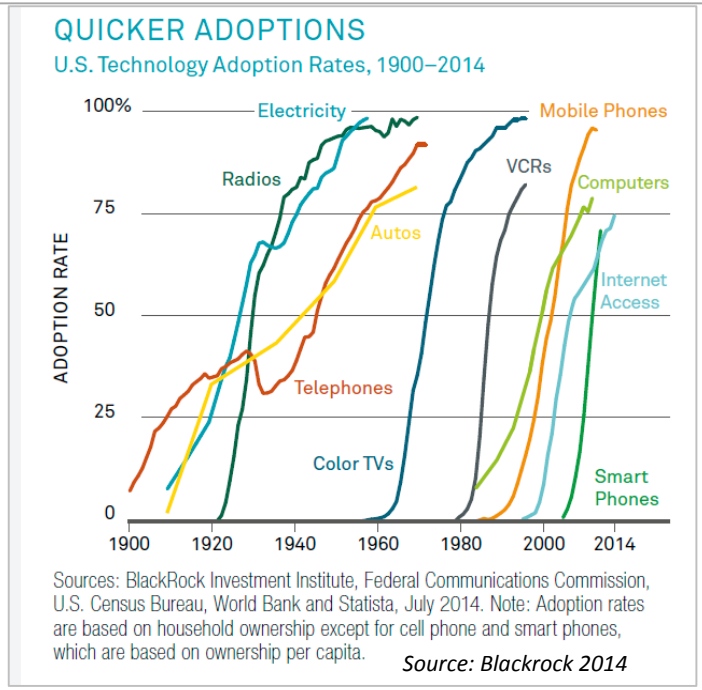
Electric Vehicle Diffusion and Raw Materials Supply Chains

- After multifold growth in 2011 and 2012, EV stock growth seems to be settling. Battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV) stocks grew by 80% and 75% in 2015, and 86% and 83% in 2014, respectively.
- Despite these high growth rates, the share of electric cars in the total stock is only **0.1%**.
- *IEA models a target of **10%** of total stock in 2030 (**150 million EVs**) and **40%** in 2050 (**1 billion EVs**).
- Bloomberg New Energy Finance (BNEF) forecasts EV stock to reach 400 million by 2040 and annual sales to reach **41 million** in 2040, **35%** of all new light duty vehicles sales in that year.
- Many technologies were adopted rapidly in the U.S.
  - Car ownership reached 80% in 50 years.
  - 100% adoption took only 40 years for electricity, 25 years for mobile phones.
  - Even faster adoption rates were observed in smart phones and computers.
- ***Will EVs exhibit similar "S-curves"?*** Considerations included cost of batteries, which is influenced by minerals supply chains, infrastructure requirements (e.g., charging stations), existence of convenient alternatives, and performance expectations of consumers (e.g., range of travel).





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*International Energy Agency (IEA) scenarios model a set of climate change policy targets that are theorized to keep global warming within 2 Degree Celsius.

What are the materials risks for battery manufacturing?

Normalized material criticality in 2013 on a scale of 0 to 1 (1=high risk)

Materials	Criticality	Supply risk	Production growth	Market dynamics
Cobalt	0.34	0.29	0.49	0.27
Lithium	0.13	0.12	0.43	0.04
Rare earth	0.48	0.76	0.30	0.49

Source: National Science and Technology Council (US) 2016

NSTC (2016) methodology:

- The **supply risk** indicator utilizes the Herfindahl-Hirshman Index and the Worldwide Governance Indicator (World Bank) of supplying countries to assess geopolitical risk. If countries with low WGI scores have high market shares, supply risk is higher.
- The **production growth** indicator is based on average annual growth rate of production over 5 years. The assumption is that faster growth must imply increased reliance on development of new geological resources, with all of the associated risks of resource development, rather than growth in secondary markets.
- The **market dynamics** indicator quantifies price volatility.
- **Potential criticality** is the geometric mean of the other three indices. All indices are normalized on a scale of 0 to 1, with **1 signifying the highest risk**.

Shortcomings of the methodology:

- According to this methodology, lithium production growth risk is lower because production declined by 7% since 2013. *However, this conclusion is misleading because there are capacity constraints at least in the short-term. Supply from secondary sources can also complicate the relevance of this metric.**
- Lithium's spot prices rose **more than 100%** in 2015-16, which would cause market dynamics metric to indicate increased risk. *However, this price increase appears to be temporary as long term contract prices remain low.*
- **Cobalt supply is critical** as 55% of global mine production comes from Congo (Kinshasa) and Zambia. *Even though this methodology assigns a lower supply risk (0.29) to cobalt, an improved metric would include not only production concentration, but also reserve concentration.*
- **Rare earths production** is still very much concentrated in China with 85% production share. Australia, however, increased its global production share from 1.8% in 2013 to 8% in 2015

* For a discussion of supply chain risks, see our Research Note from April 2016.

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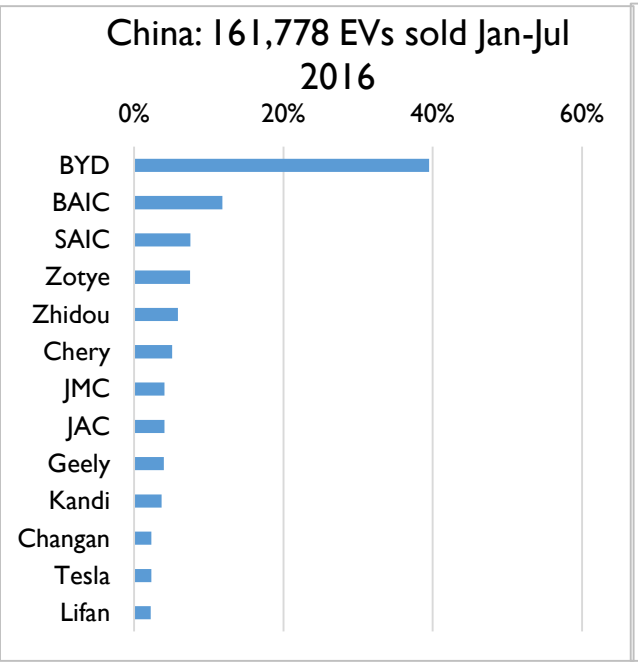
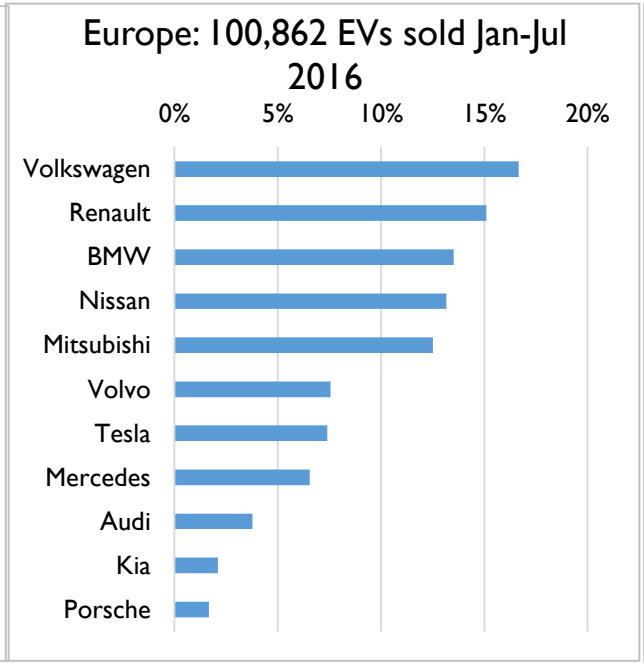
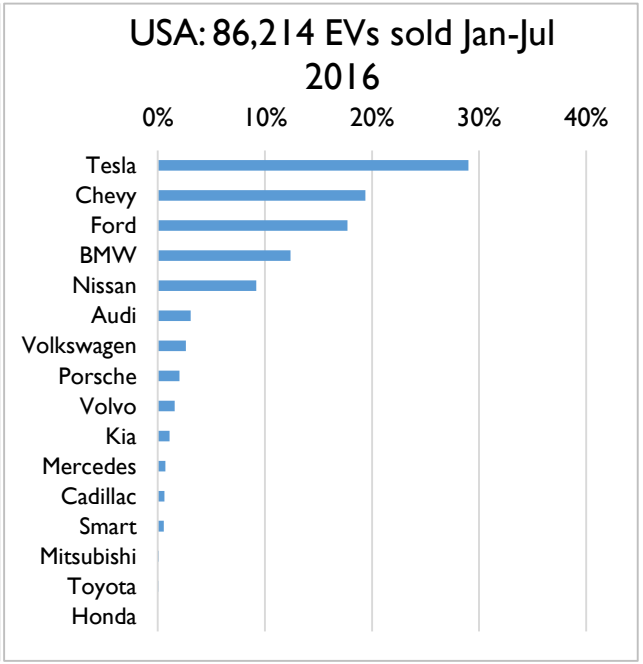
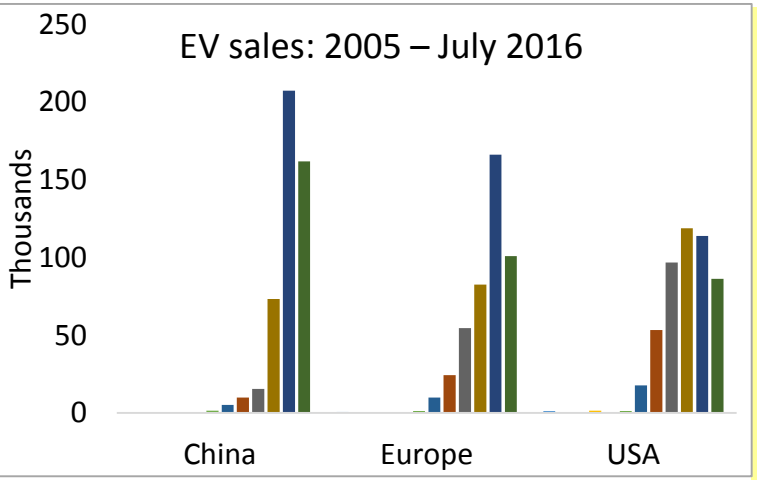
EV Sales: China overtook Europe and USA; many companies in the sector, different companies dominate each market









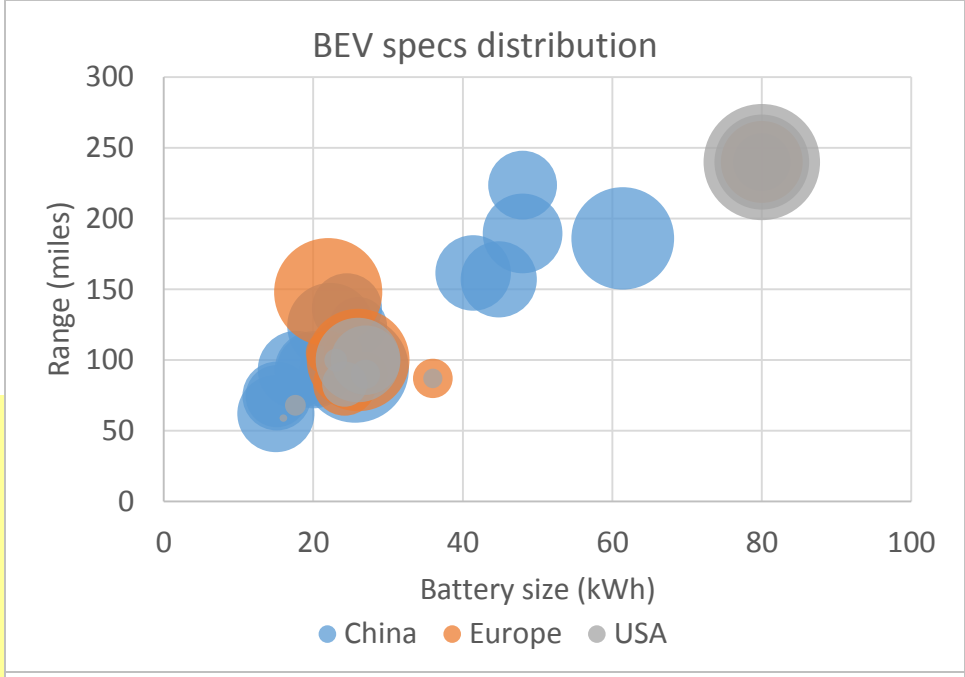
2016 sales appear on track to surpass 2015 sales in all three markets. If sales continue at the same pace, 2016 EV sales can exceed 700,000.

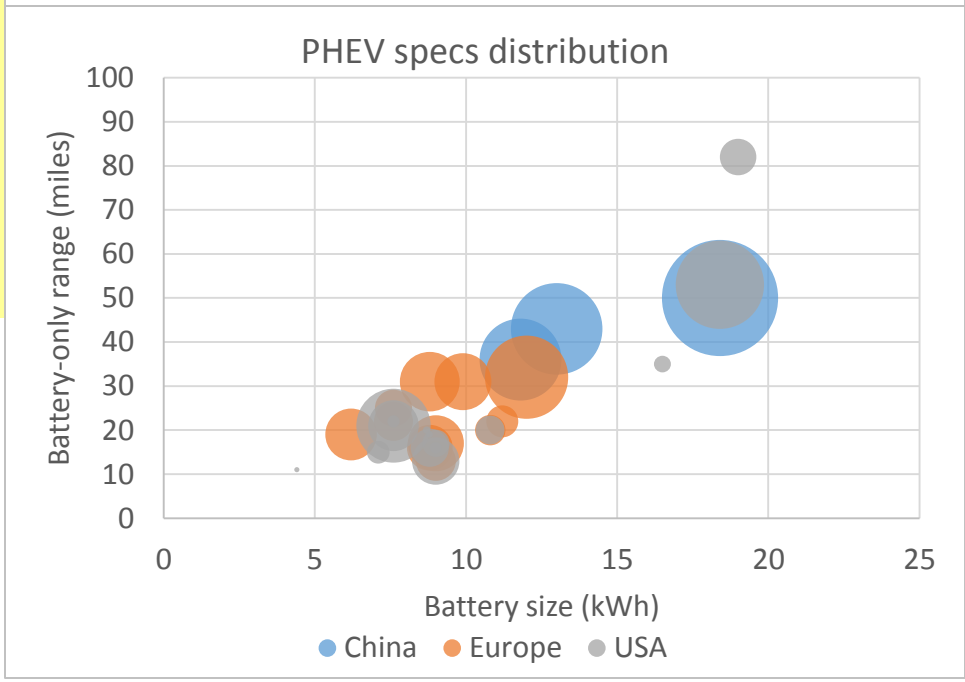
- **Lithium carbonate content** requirement would be **12,000** metric tons (mt) LCE. 2015 **Global lithium production** was approximately **173,000** mt LCE.
- To reach BNEF's forecast of 41 million EV sales in 2040, the annual sales will need to grow at 18% annually, putting significant strain on the lithium supply chain.
- **Cobalt content** requirement would be **3,700** mt. 2015 **Global cobalt production** was **124,000** mt.
- Cobalt demand will grow more slowly than lithium demand as many battery manufacturers are moving to low-cobalt chemistries.

Data sources: EV Obsession, U.S. Bureau of Transportation Statistics, IEA, Argonne National Laboratory, company financial reports

Battery Size, Performance and Materials Requirements are Linked

- **Battery size** has a significant impact on materials requirements.
- **Most of the PHEVs have small batteries**. The battery size is less than 15 kWh with the exception of a few luxury models.
- **BEVs have wider range** of battery sizes.
- **China** has more options in all ranges.
- The **U.S.** has either long range or short range models as of now.
- **Europe** has short range and medium range models.





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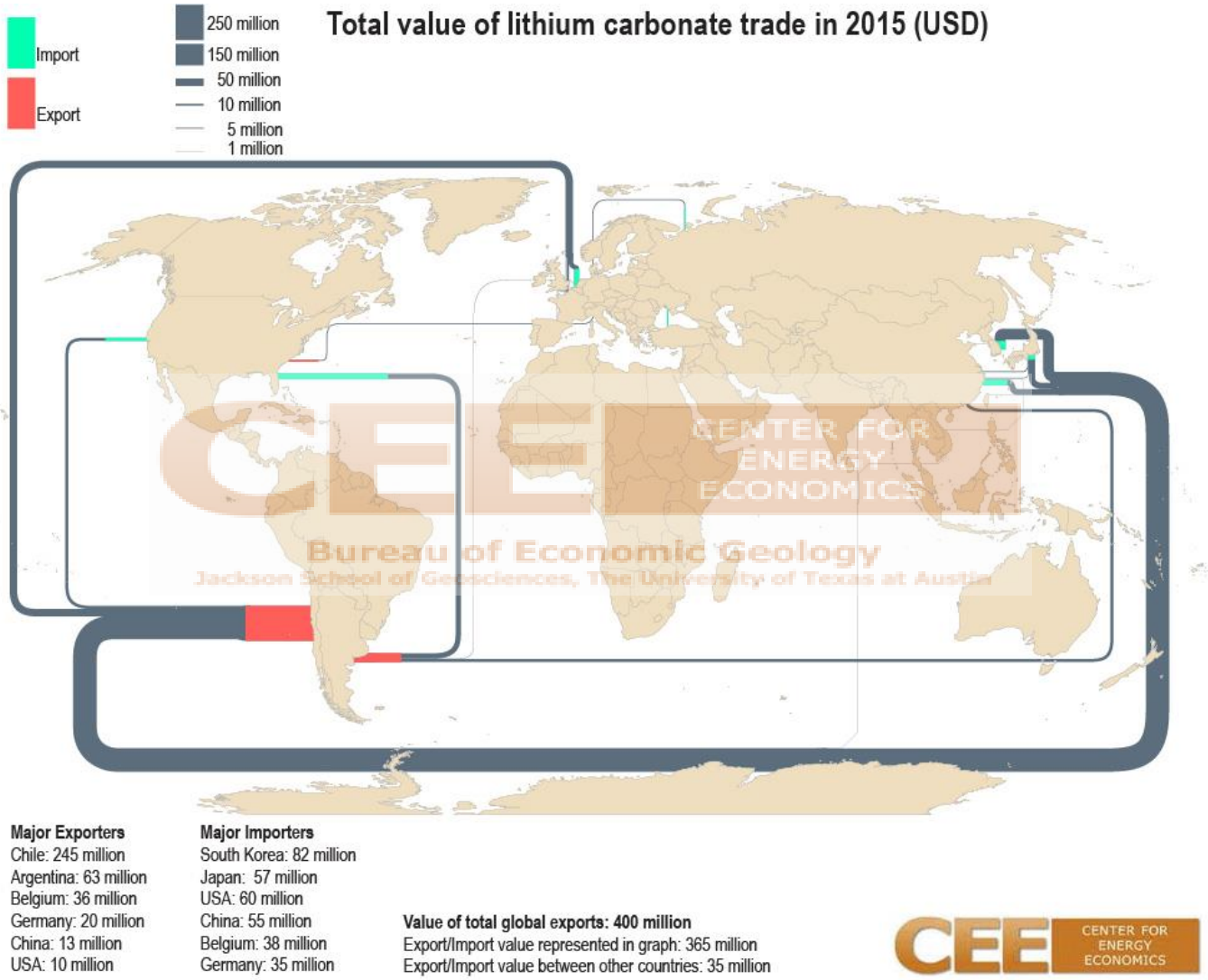
Data sources: EV Obsession, Argonne National Laboratory, U.S. Bureau of Transportation Statistics, IEA, company financial reports

Lithium Carbonate Trade Flows

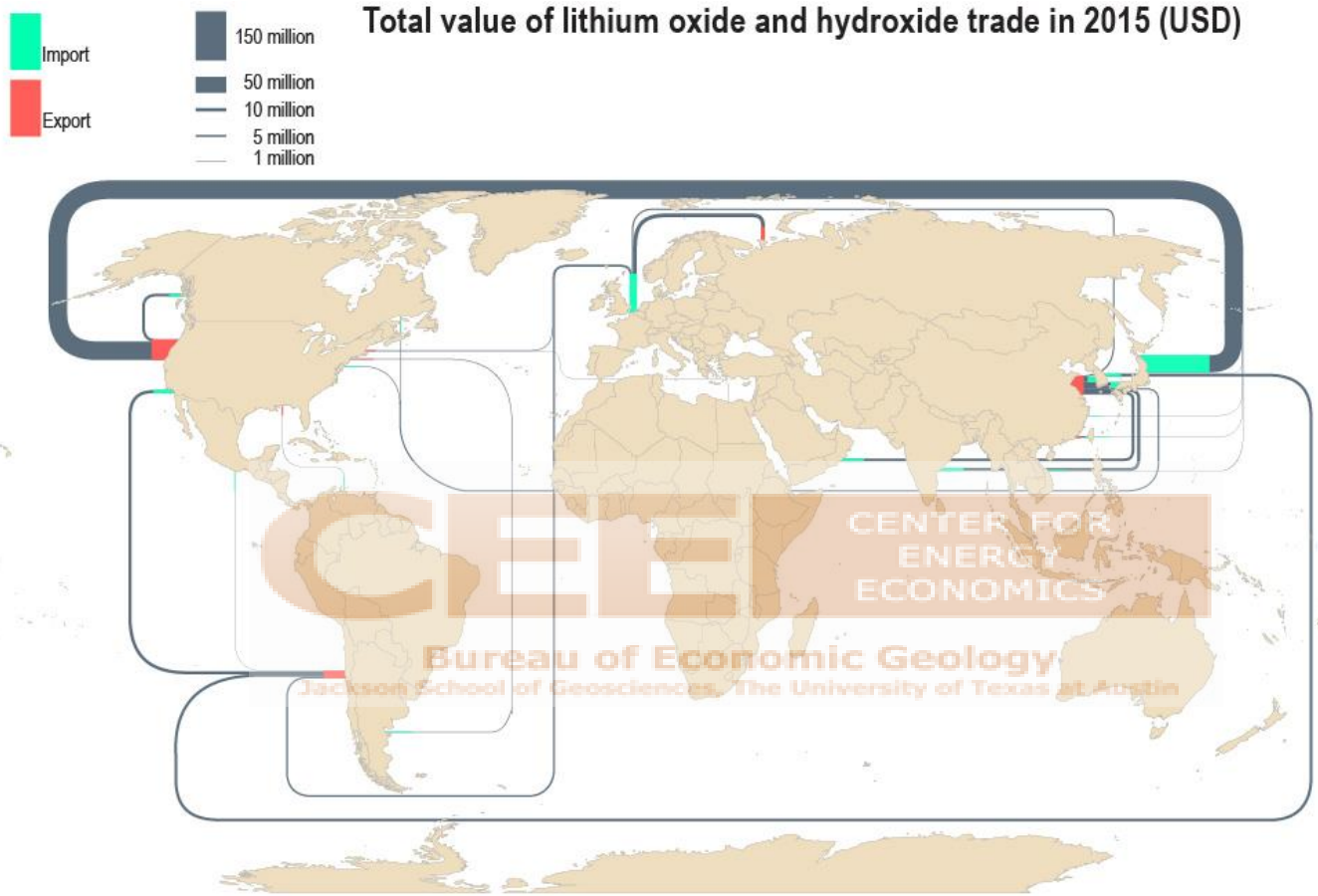
- **Chile is by far the largest lithium carbonate exporter by value, followed by Argentina.**
- The next four largest exporters (Belgium, Germany, China, and USA), are also four of the largest importers. **All four are net importers in terms of value.**
- Lithium carbonate is also used to manufacture **other widely traded compounds** like lithium oxides and hydroxide (see next slide).
- South Korea and Japan are **major importers with no significant exports**.
- South Korea and Japan also have **some of the largest battery manufacturing facilities**.



Data source: International Trade Center www.trademap.org

Lithium Oxide and Hydroxide Trade Flows

- **The U.S. is the largest exporter** of lithium oxide and hydroxide compounds, but **only a small quantity is domestically produced**.
- Combining lithium carbonate, oxide, and hydroxide, **the U.S. exports a net value of $ 17 million**. Comparatively, **China exports a net value of $30 million**.
- **Chile is a large exporter** of lithium oxide and hydroxide as well with **no significant imports.**
- Japan and South Korea are again the **largest importers with no significant exports.**



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