RELEVANCE
Lithium-ion batteries (LIBs) have emerged as the battery of choice for rapidly growing markets in electric vehicles and grid electricity storage.

Challenges in the supply chain of raw materials include:
- Possibility of demand for lithium, graphite, cobalt, and nickel could outstrip current supply of virgin material
- Concentration of mining in only a few countries
- Supply risk due to government instability in origin countries
- Risk of price increases.

Recycling of LIBs would ease supply shortages allowing continued growth of beneficial markets.

OBJECTIVE: Define the future economic role of recycling of LIBs.

SUMMARY
This project provides a comprehensive view of global trends in supply and demand for materials critical for LIBs and the processes needed for recycling to contribute to the circular economy of these materials. To date, we have:
- Quantified the current state of global supply of raw materials
- Elucidated the global manufacturing and trade flows associated with LIBs
- Analyzed the LIB manufacturing value chain
- Benchmarked the current state of LIB recycling.

These analyses provide the basis for modeling the potential for LIB recycling to provide critical materials for continuing manufacturing of new batteries in the future.

FUTURE WORK/ CHALLENGES & BARRIERS
Tasks 2 and 3 of this project—quantifying the economics of battery recycling and modeling LIB recycled material supply curves—will be completed in Fiscal Year (FY) 2018 and FY 2019.

Future initiatives include a more comprehensive analysis of the “reverse supply chain” for LIBs, including analysis of policies and programs for recovering materials from end-of-life vehicles, vehicle disassembly, and geographic considerations for battery recycling operations.

Environmental and energy impacts of LIB recycling versus use of virgin materials will also be a focus of future research.

COLLABORATION AND ACKNOWLEDGEMENTS
We are partnering with Argonne National Laboratory

APPROACH
Task 1. Quantify global trends in supply and demand for materials critical for LIBs
- Milestone: Update the LIB critical material supply chain and trade flows maps
- Understand trends in vehicle sales, and stationary battery deployment to estimate future battery materials demand
- Quantify trends in battery capacity, material use, and battery manufacturing technologies
- Quantify the time-dependent supply of spent LIB battery materials

2017 Global Mine Production of LIB Materials*

Task 2. Quantify the economics of battery recycling accounting for regional differences
- Milestone: Time and location dependent cost for recycled LIB materials – June 30, 2018
- Working in concert with the Argonne ReCell team, develop cost parameters for the three most common recycling processes

Employ NREL’s unique CEMAC international manufacturing cost models to estimate recycling process costs accounting for regional differences in labor, energy, transport, regulatory compliance, and other costs.

Task 3. Model the dynamic relationships between demand, supply, and economics to quantify the potential contribution of LIB recycling
- Milestone: Integration of global supply chain values from Tasks 1 and 2 with Argonne ReCell model – September 30, 2018
- Model dynamic material supply and demand curves based on the cost and supply chain values developed in Tasks 1 and 2.

ACCOMPLISHMENTS
Task 1 – Updates to LIB Supply Chain Data and Maps
In 2017, 32 countries accounted for all production of the raw materials needed for nickel manganese cobalt (NMC) batteries. Supply risk is high for some raw materials:
- Cobalt: In 2016, 54% of the supply was mined in the Democratic Republic of the Congo; the U.S. Department of Energy has deemed cobalt near-critical supply risk
- Natural Graphite: Deemed a critical supply risk by the Joint Research Centre in the European Commission, and the Royal Society of Chemistry primarily because of the very high concentration of both production and reserves in China
- Lithium: Potential short-term supply risk because of a long development lag for production from new mines

An update of regional LIB supply chain and trade flow maps highlights the rapid evolution in global LIB manufacturing.
- Global LIB manufacturing capacity grew from 76,255 megawatt-hours (MWh) to 189,762 MWh between 2014 and 2017.
- LIB manufacturing capacity is rapidly shifting from consumer electronics to vehicles. In 2014, 36% of global capacity was devoted to vehicles. In 2017 it rose to 60%.

Task 3 – Modeling of Economic Potential for LIB Recycling
Existing LIB recycling facilities predominantly use pyrometallurgy and hydrometallurgy processes
- Facilities are not exclusively recycling LIBs (also nickel-metal hydride and nickel-cadmium batteries); mixed battery types are acceptable because materials are recovered as elemental metals
- Hydrometallurgy: LiCO3, Al, Co, and Ni are recovered. Anode is destroyed.
- Pyrometallurgy: only Co and Ni are recovered

2017 Sources: BNEF 2017; Avicenne 2017; NREL analysis 2018

*Mill or smaller production for aluminum
Source: U.S. Geological Survey

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