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Supply-Chain Analysis of Lithium-Ion Battery Material and Impact of Recycling

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Project ID #BAT372

Overview

Timeline

- Project start date: 2Q FY2018
- Project end date: 2Q FY2019
- Percent complete: 40%

Budget

- Total project funding
  - DOE share: 100%
- FY 2017: carryover funds: $139K
- Funding for FY 2018:$115K

Barriers

- Barriers addressed:

Recycling and Sustainability – Decreasing the cost of recycling could reduce the cost of EV batteries and prevent material shortages

Partners

- Interactions/collaborations:

  Argonne National Laboratory
- Project lead:

  Margaret Mann

Relevance

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

Challenges in the supply chain of raw materials:

- Demand for lithium, graphite, cobalt, and nickel could outstrip 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

Goal: Define the future economic role of recycling of Li-ion batteries.

Milestones

- Update of the Li-ion battery (LIB) material supply chain and trade flows maps (Task 1) - **complete**
- Time and Location Dependent Cost for Recycled LIB Materials (Task 2) – 6/30/2018
- Integration of global supply chain values from Tasks 1 and 2, with ANL ReCell model (Task 3) – 9/30/2018
- Publication of study results – 12/31/2018

- Gantt chart

Approach

Tasks:

1. Quantify global trends in supply and demand for materials critical for Li-ion batteries
2. Quantify the economics of battery recycling accounting for regional differences
3. Model the dynamic relationships between demand, supply, and economics to quantify the potential contribution of LiB recycling

This project will be conducted in collaboration with researchers from ANL, to evaluate the dynamic relationship between material supply and manufacturing cost.

Approach – Task 1

Quantify global trends in supply and demand for materials critical for Li-ion batteries

- Milestone: Update the Li-ion battery (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

Approach – Task 2

Quantify the economics of battery recycling accounting for regional differences

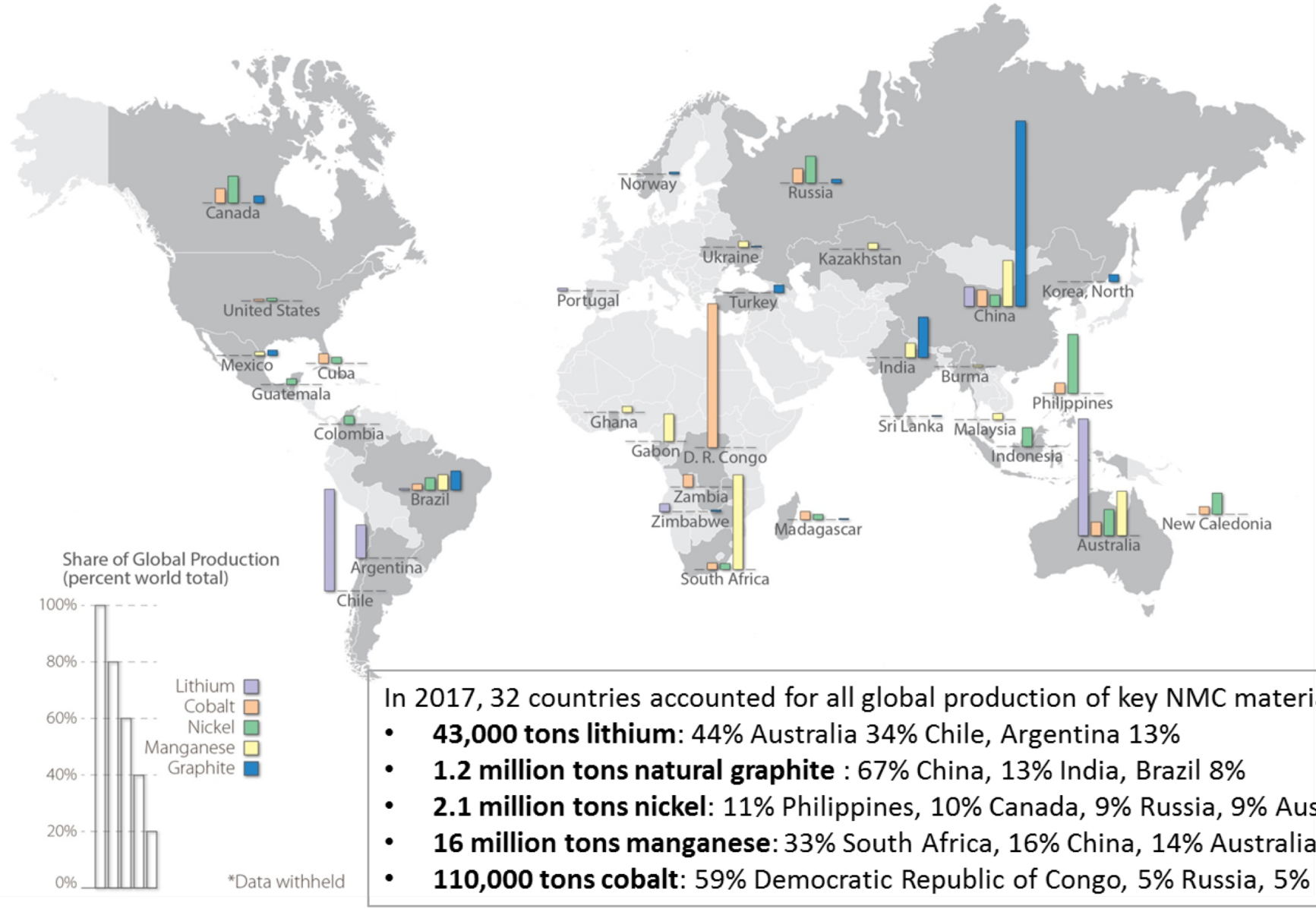
- Time and Location Dependent Cost for Recycled LIB Materials (Task 2) – 6/30/2018
- Working in concert with the Argonne ReCell team, develop cost parameters for the 3 most common recycling processes
  - Energy use
  - Labor requirements
  - Capital equipment
  - Variable and fixed operating parameters
- 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.

Approach – 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 ANL ReCell model – 9/30/2018
- Model dynamic material supply and demand curves based on the cost and supply chain values developed in Tasks 1 and 2.

Accomplishments – Update Li-ion Battery Supply Chain Map

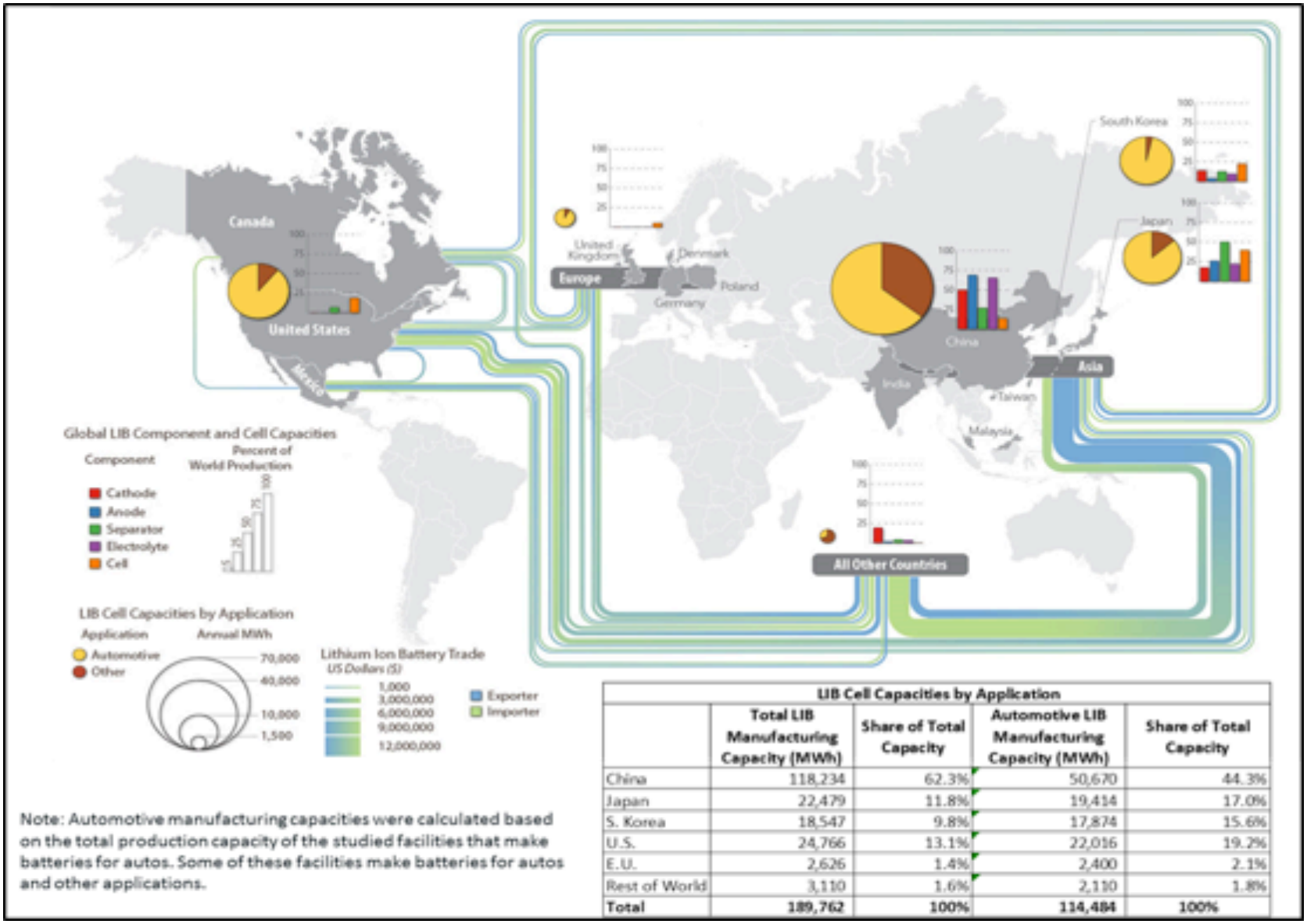


In 2017, 32 countries accounted for all global production of key NMC materials

- **43,000 tons lithium**: 44% Australia 34% Chile, Argentina 13%
- **1.2 million tons natural graphite** : 67% China, 13% India, Brazil 8%
- **2.1 million tons nickel**: 11% Philippines, 10% Canada, 9% Russia, 9% Australia
- **16 million tons manganese**: 33% South Africa, 16% China, 14% Australia
- **110,000 tons cobalt**: 59% Democratic Republic of Congo, 5% Russia, 5% Australia

Milestone 1 Li-ion Battery Supply Chain – Raw Materials

Accomplishments – International Li-ion Battery Trade Flows



LIB Cell Capacities by Application				
	Total LIB Manufacturing Capacity (MWh)	Share of Total Capacity	Automotive LIB Manufacturing Capacity (MWh)	Share of Total Capacity
China	118,234	62.3%	50,670	44.3%
Japan	22,479	11.8%	19,414	17.0%
S. Korea	18,547	9.8%	17,874	15.6%
U.S.	24,766	13.1%	22,016	19.2%
E.U.	2,626	1.4%	2,400	2.1%
Rest of World	3,110	1.6%	2,110	1.8%
Total	**189,762**	**100%**	**114,484**	**100%**

Note: Automotive manufacturing capacities were calculated based on the total production capacity of the studied facilities that make batteries for autos. Some of these facilities make batteries for autos and other applications.

Milestone 1 Li-ion Battery Supply Chain – Asian countries (China, Japan and South Korea) were the key producers of LIB for all applications in 2016

Task 2 – Refine LIB Manufacturing Value Chain

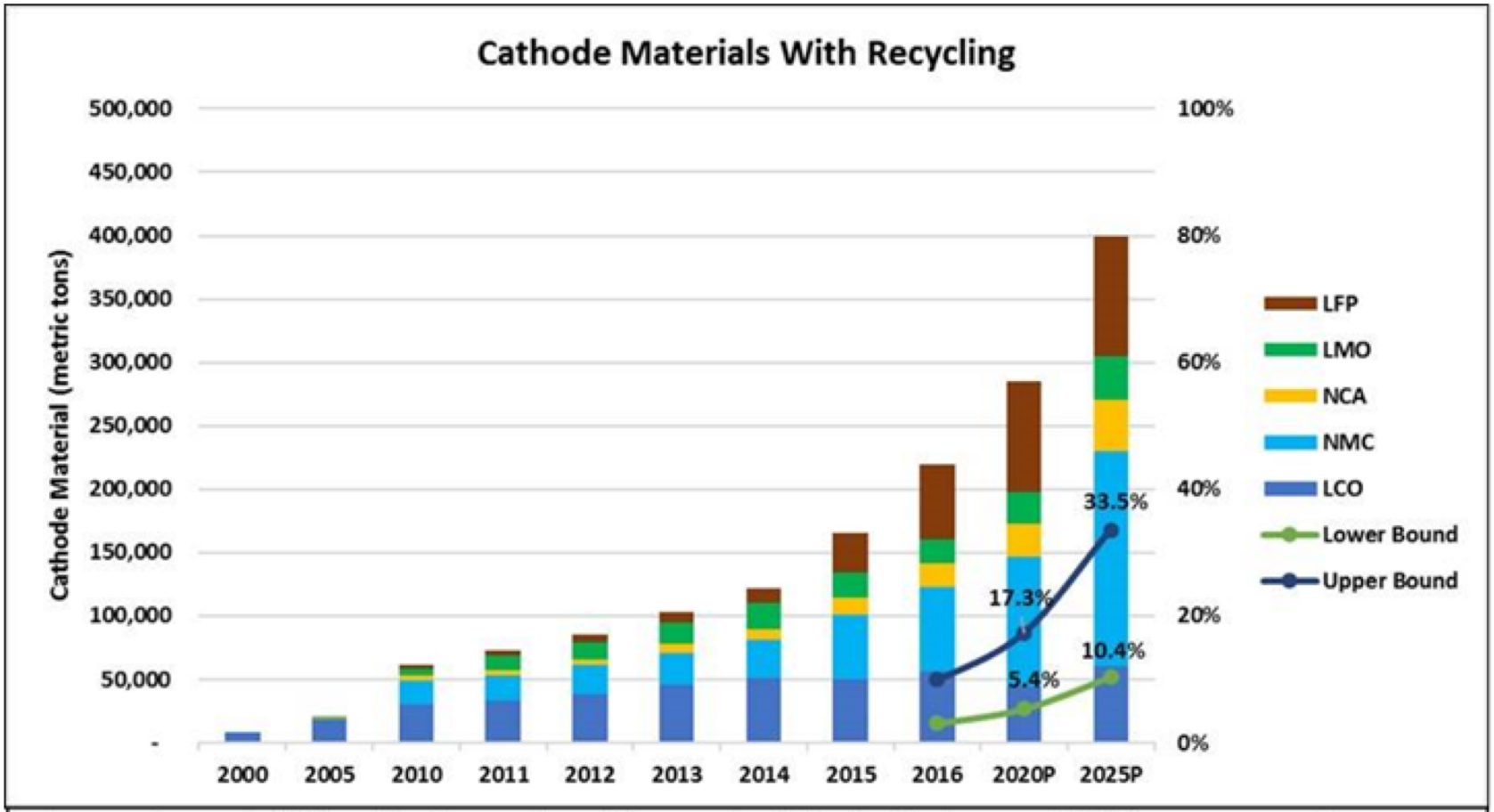
LIB Pack Value Chain in 2016 ($US/kWh)

	Raw Materials	Processed Materials	Electrodes	Cells	Battery Pack	TOTAL
VALUE ($/kWh)	$50	$118* [$84]	$28*	$146* (cum. $342*)	$74	$416 [$332]
SHARE [With Recycled materials]	12% *[n/a]*	28% [25%]	7% *[8%]*	35% *[44%]*	18% *[22%]*	100% [100%]
CURRENTLY PRODUCED	Globally	Globally	Regionally	Globally	Regionally	
SUPPLY CHAIN ISSUES	•Supply risk of some critical materials (e.g., Co, Li and Gr) •Demand may exceed supply in the near-term	•Critical to produce quality cells •Demand assurance •Recycling can help narrow the gap between supply and demand	•Critical to quality • Regional supply chain clusters in Asia •Emerging supply chains in North America and Europe	•Critical to quality • Regional supply chain clusters in Asia • Emerging supply chains in North America and Europe	•Proximity to customers: shipping costs, exchange of technical specifications	

- Assumed energy storage requirement is 10 kWh for PHEV LIB pack
- Factory gate – shipping from Asia to the West Coast of the United States adds approximately $7/kWh (Chung et al. 2015)

Value chain analysis for PHEV battery with virgin and recycled materials [cost in dollars of LIB pack with recycled materials is shown in the square brackets] (Sources of data: NREL analysis 2018; BNEF 2017, Avicenne 2017)

Task 2 – Analyze LIB Material Demand and Recycling Potential

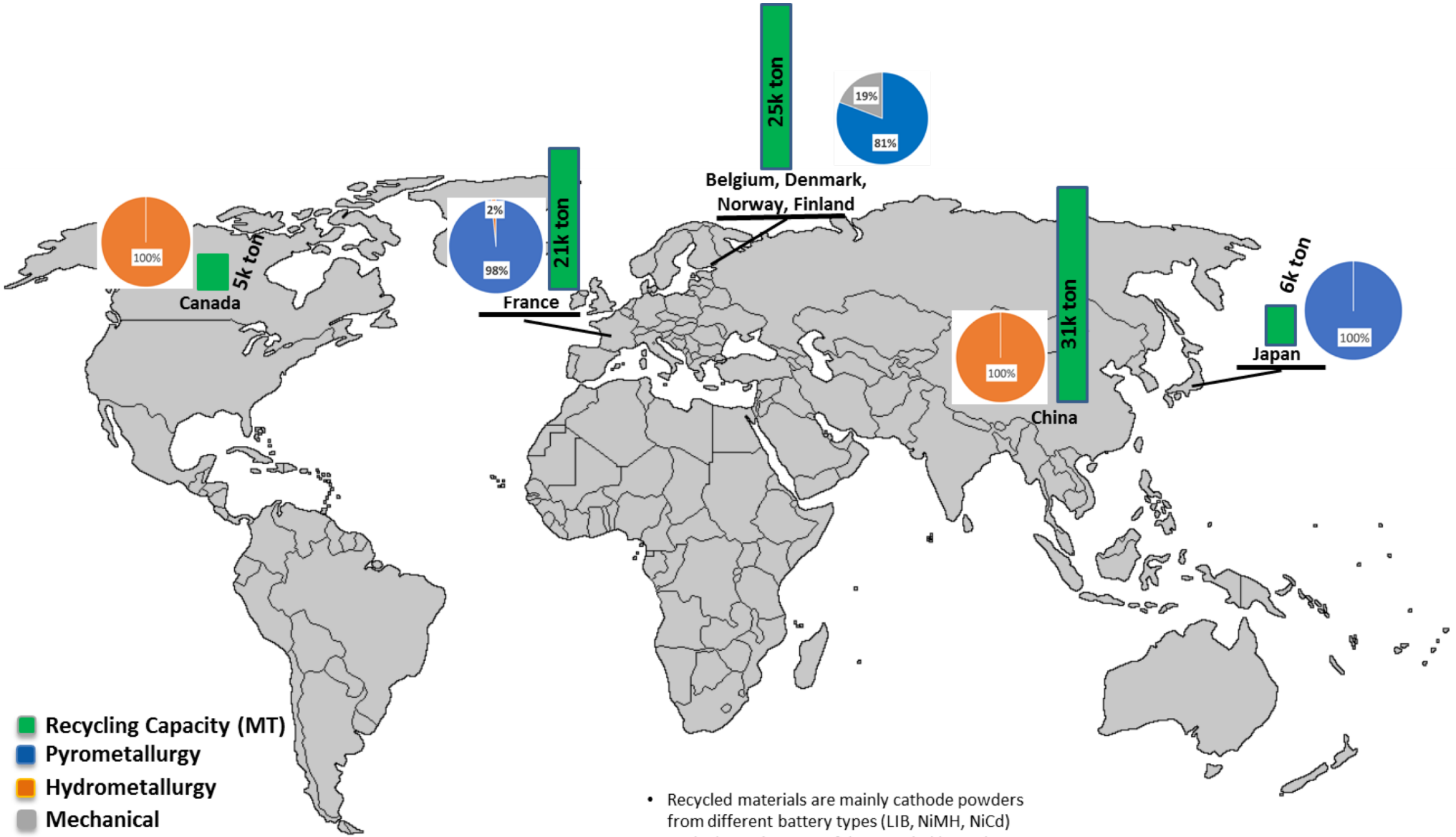


- Lower bound: 50% collection rate of the end-of-life batteries and 50% recovery rate
- Upper bound: 90% collection rate of the end-of-life batteries and 90% recovery rate
- Percentages represent potential of cathode materials demand filled by recycled materials

Projections of LIB Cathode Material Demand and Potential Near-Term Recycling

- Average battery life assumed to be 10 years, using the expected lifetime of automotive LIBs as a proxy of average life for all LIB end-uses.

Task 3 – Model Economic Potential for LIB Materials Recycling



- Recycled materials are mainly cathode powders from different battery types (LIB, NiMH, NiCd)
- LIB is the major type of the recycled batteries

Source of date: Heelan et al. 2016; Siret 2012, JRC 2016, NREL Analysis 2018

LIB Recycling in 2016

Journal Articles and Conferences

Ahmad Mayyas. Toward Greater Understanding of Upstream and Downstream Manufacturing Processes of Automotive Li-ion Batteries. Advanced Automotive Battery Conference, June 19-22, 2017, San Francisco, California.

Upcoming Publications

Ahmad Mayyas, Darlene Steward, Margaret Mann. *"Recycling of Li-Ion Batteries: Current Challenges and Outlook on the Supply Chain". Sustainable Materials and Technologies* (2018).

Darlene Steward, Ahmad Mayyas, Margaret Mann. "Economics and Challenges of Li-Ion Battery Recycling" 16th Global Conference on Sustainable Manufacturing, October 2-4, 2018 Lexington Kentucky

Upcoming Conferences

- Ahmad Mayyas. Impacts of Recycling on The Global Supply Chain of Li-Ion Batteries. The Cobalt Conference, May 23-24, 2018, Las Vegas, Nevada.
- Ahmad Mayyas. Manufacturing Competitiveness of the Recycled Li-Ion Battery Materials. Advanced Automotive Battery Conference. June 4-7, 2018, San Diego, California

Future Work

Tasks 2 and 3 of this project; Quantify the economics of battery recycling, and modeling of LIB recycled material supply curves will be completed in 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 v. use of virgin materials will also be a focus of future research.

Summary

This project provides a comprehensive view of global trends in supply and demand for materials critical for Li-ion batteries (LIB) 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 of the potential for LIB recycling to provide critical materials for continuing manufacture of new batteries in the future.

Thank You

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