CLOSING THE LITHIUM-ION BATTERY LIFE CYCLE

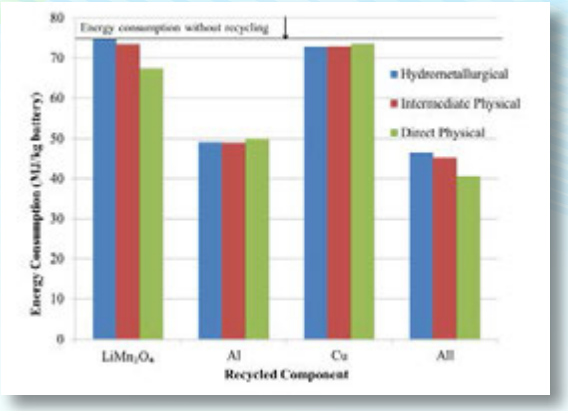
Linda L. Gaines and Jennifer B. Dunn
Argonne National Laboratory
9700 S. Cass Avenue, Argonne, IL 60439

Electric drive vehicle sales are growing worldwide. The key component in these vehicles is the lithium-ion (Li-ion) battery. While it is possible to extend the life of Li-ion batteries in applications such as grid storage, eventually they reach their end-of-life (EOL).

Why Recycle?

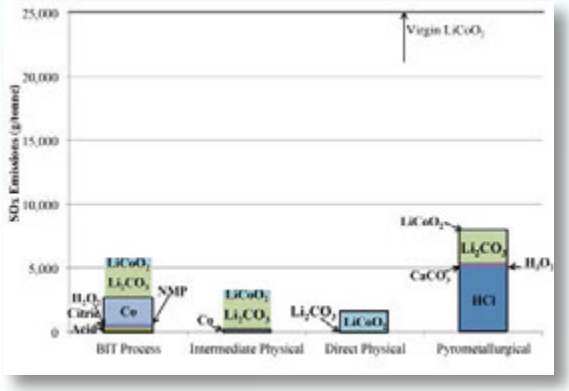
- To reduce net energy requirements
- To reduce environmental impacts
- To reduce potential supply constraints by replacing extracted materials with recovered materials
- To generate cost-offsetting revenues
- To comply with government mandates for EOL battery recycling

Recycling Multiple Items Increases the Savings (this example is for a $LiMn_2O_4$ cathode)



Energy savings and emissions benefits are maximized by recovering as many materials in as-close-to usable form as possible.

Recycling Cobalt- or Nickel-based Cathodes Minimizes Sulfur Emissions



Benefits depend on the cathode chemistry; sulfur emissions reductions from using recycled material are greatest for cathodes whose elements are mined from sulfide ores.

Recovery of Cathode Material Maximizes Product Value

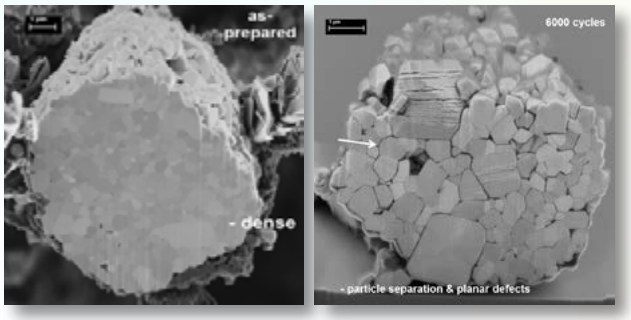
Cathode	Price of Constituents ($/lb)	Price of Cathode ($/lb)
$LiCoO_2$	8.30	12–16
$LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$	4.90	10–13
$LiMnO_2$	1.70	4.50
$LiFePO_4$	0.70	9

The current pyrometallurgical recycling process recovers cobalt, nickel, and copper, whose high value drives the business case. (The aluminum and lithium are entrained in a slag.) However, the value of elements recovered would be much lower for newer cathode formulations. Processes to recover additional materials and even reusable cathode material are available or under development. These could make recycling of all Li-ion chemistries economical.

Research is Underway to Address These Barriers to Recycling:

- Methods for collection
- Identification and sorting
- Transportation-related safety and regulatory issues
- Product quality and utility after use (see figure below)
- Needed process development to ensure high-valued products
- Battery design elements that affect disassembly

Material Degradation after Repeated Use



Electron microscopy images of a Li-ion battery material (NCA cathode) as prepared (left) and after 6,000 cycles of use (right) show primary particle separation and defects in highly cycled samples, which are absent in as-prepared samples. These changes reduce battery performance during continued cycling. (Photos courtesy of D. Abraham and D. Miller, Argonne National Laboratory).

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Several types of recycling processes are available, recovering materials usable at different stages of the production cycle — from metallic elements to materials that can be reused directly in new batteries. Recovery closer to final usable form avoids more impact-intensive process steps. Portions courtesy of Umicore, Inc.

http://www.transportation.anl.gov/technology_analysis/battery_recycling.html

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