HOW GREEN IS BATTERY RECYCLING?

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Introduction

How can we minimize the life-cycle impacts of using lithium-ion batteries in cars?

- We compare the potential of several recycling processes to displace virgin materials at different process stages (Figure 1).
- Although few automotive batteries have been produced, work is under way to develop the best processes to recycle these batteries when they are no longer usable in vehicles.
- Secondary use of the batteries could delay the return of material for recycling, thus increasing the demand for virgin materials and the resultant life-cycle impacts.

Relation to the 12 Principles of Green Chemistry

- Prevention. Recycling keeps material out of the waste stream both at product end-of-life and from production processes for virgin materials that are displaced.
- Atom Economy. Recycling minimizes the use of new materials.
- Design for Energy Efficiency. Energy and environmental impacts for recycled materials are generally lower than those for virgin materials.
- Use of Renewable Feedstocks. Use of recovered materials should be preferable to use of renewable ones!
- Design for Degradation. We think design for multiple long lives is a better principle.

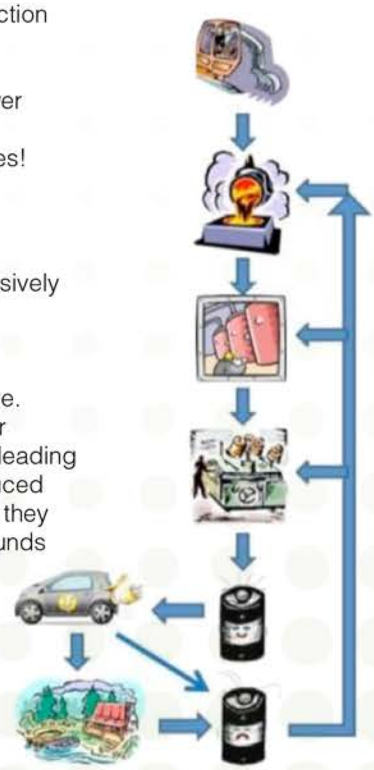

Figure 1 Recycled material displaced

How Batteries Are Made

Roughly half of battery mass consists of materials (copper, steel, plastics, aluminum) that have been extensively documented in previous analyses. Therefore, we focus on the active battery materials that are not as well characterized. Production steps are shown schematically in Figure 2.

The cathode (positive electrode) material is a metal oxide, with lithium ions inserted into the crystal structure. Commercial electronics batteries generally use cobalt, but oxides containing nickel, manganese, and other elements are being developed for vehicle batteries. Both cobalt and nickel are smelted from sulfide ores, leading to significant sulfur dioxide emissions, even from plants with extensive controls. Lithium carbonate is produced from salars (large brine lakes), mostly in Chile. Brines are concentrated in ponds for over a year, and then they are treated with soda ash. The carbonate precipitates and is filtered out and dried. Active cathode compounds are made from lithium carbonate and metal salts by chemical replacement reactions in solution. High-temperature treatment may be required to produce the desired configurations.

The anode (negative electrode) is generally made of graphite. To eliminate detrimental oxygen-containing species on the surface, it is baked at 2,000°F (1,100°C) in a reducing or inert atmosphere. Additives are mixed in to make the anode paste. The electrode materials are spread onto thin metallic foil substrates, which also serve as the current collectors. For the cathode, aluminum foil (about 20 µm thick) is used, and for the anode, copper (about 14 µm thick) is used.

Separators for Li-ion batteries are typically made from polyolefins using 3- to 8-µm layers (PP/PE/PP or just PE). The porous film keeps the electrodes apart, and if the cell becomes too hot, melts and closes off the pores, thereby shutting off the cell current. The electrodes and separator are rolled up together and placed in cans before addition of the electrolyte, which is usually a dilute solution of a fluorine-containing lithium salt in an organic solvent. Assembled cells are conditioned and tested.

Recycling Processes

Recycling can recover materials at different production stages, from basic building blocks to battery-grade materials. The chart in Figure 2 is marked with symbols to show where three current recycling processes can recover materials. Impacts from all process steps above the symbols are avoided.

■ SMELTING

At one extreme are smelting processes that recover basic elements or salts. These are operational now on a large scale and can take just about any input, including different battery chemistries (including various Li-ion, Ni-MH, etc.), or mixed feed. Smelting takes place at high temperature, and organics, including the electrolyte and carbon anodes, are burned as fuel or reductant. The valuable metals (Co and Ni) are recovered and sent to refining so that the product is suitable for any use. The other materials, including lithium, are contained in the slag, which is now used as an additive in concrete. The lithium could be recovered by using a hydrometallurgical process, if justified by price or regulations.

▲ DIRECT RECOVERY

At the other extreme, recovery of battery-grade material has been demonstrated. Such processes require as uniform feed as possible, because impurities jeopardize product quality. The components are separated by a variety of physical and chemical processes, and all active materials and metals can be recovered. It may be necessary to purify or reactivate some components to make them suitable for reuse in new batteries. Only the separator is unlikely to be usable, because its form cannot be retained. This is a low-temperature process with a minimal energy requirement. Almost all of the original energy and processing required to produce battery-grade material from raw materials is saved.

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● INTERMEDIATE PROCESS

The third type of process is between the two extremes. It does not require as uniform a feed as direct recovery, but recovers materials further along the process chain than does smelting.

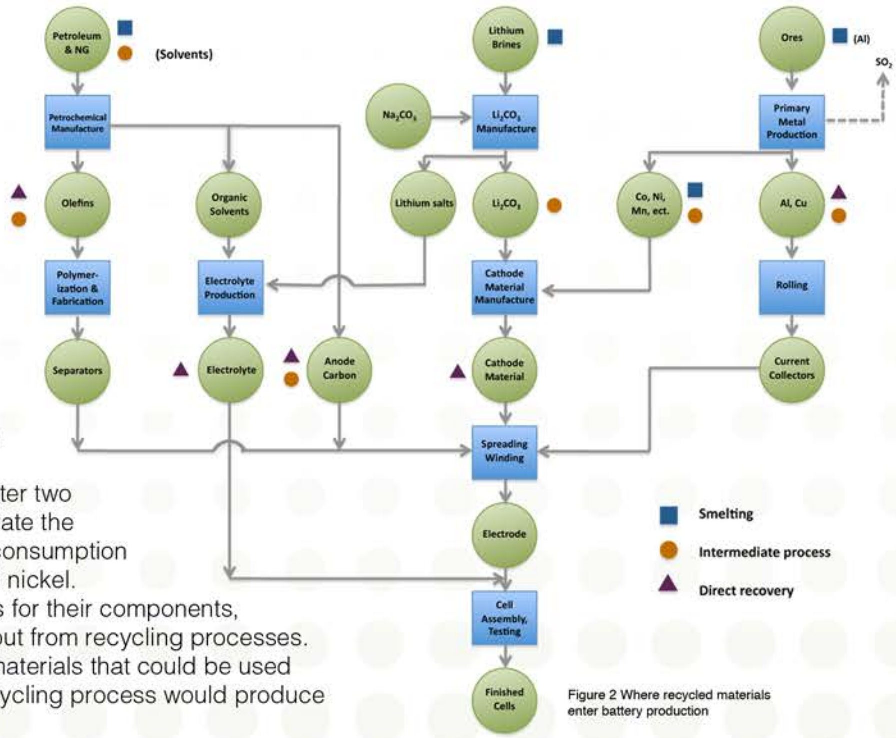

Figure 2 Where recycled materials enter battery production

Comparison of Recycling to Primary Production

In Figure 3, we see that a large percentage of the battery production energy is consumed during assembly and testing and cannot be recovered by recycling. If the battery can be used again, however, the energy use and emissions per use are divided among service lives. Once the battery is no longer usable, it can still be recycled, although some of the materials may be more degraded after two uses and therefore require more processing. Metals illustrate the benefits of recycling, as the percent reduction in energy consumption ranges from about 25% for steel to 75% for aluminum and nickel. Advanced batteries will likely require high-grade materials for their components, so it will be important to understand the quality of the output from recycling processes. A closed-loop battery recycling process would produce materials that could be used in the production of new batteries, while an open-loop recycling process would produce materials that would be used in another product.

Enablers of Recycling and Reuse

Material separation is often a stumbling block for the recovery of high-value materials. Therefore, design for disassembly or recycling would be beneficial. Similarly, standardization of materials would reduce the need for separation. In the absence of material standardization, labeling of cells would enable recyclers to sort before recycling. Standardization of cell design, at least in size and shape, would foster the design of automated recycling equipment. Standardization would also be beneficial to reuse schemes, where cells from various sources would be tested and repackaged in compatible groups for use by utilities or at remote locations.

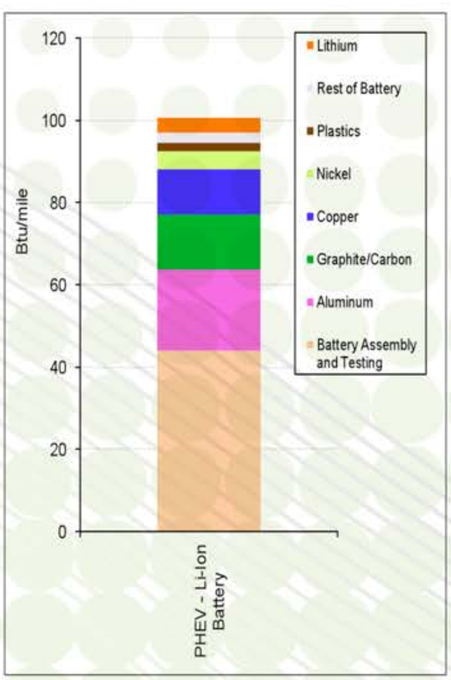

Figure 3 Energy use for battery production steps

Why Michigan?

Locating a recycling facility close to a large battery manufacturing plant, such as the one recently announced by LG Chem in Holland, MI, would have synergistic effects. Even before any post-consumer batteries are available for recycling, the recycling plant could utilize prompt manufacturing scrap — as well as rejects from battery testing — as feedstock. This approach reduces the impacts associated with using virgin materials and would help expand the battery recycling infrastructure to one that can accommodate new battery chemistries more expeditiously. Transportation costs would be minimal, and utilization of a single, known chemistry would enable the recovery of materials that could easily be put directly back into batteries. As a result, battery manufacturers would also benefit, because they could obtain low-cost materials, and the recyclers would benefit from their experience as the first in the field.

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