Battery Sustainability: End-of-Life Hierarchy

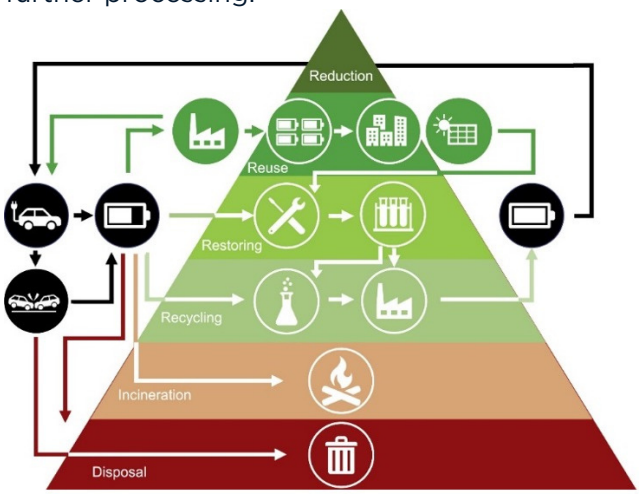
The sustainability of batteries is dependent upon a confluence of factors, from the unique chemistries of different battery types to the sourcing of primary materials. Nonetheless, one of the most critical aspects of battery sustainability is how they are dealt with following primary use. Battery end-of-life is typically defined as when 70-80% of the original energy capacity remains.

There is a clear hierarchy of sustainable solutions at their "end-of-life".From the most sustainable solution of reducing rare, hazardous, or difficult to recover materials to the least sustainable option of disposing batteries, enabling a circular economy involves manufacturers designing batteries for reuse, recycling, and material recovery.

Reduction or prevention: decreasing the amount of material that is rare, dangerous, or technically difficult to recover from recycling processes will reduce the supply chain's reliance on capital or emissions-intensive processes and minimize hazardous waste. For example, cadmium-based batteries have been banned in Europe due to environmental and health concerns and significant research has targeted to find alternatives to cobalt—which has been linked to exploitative mining practices.

Reuse: designing batteries for second-life applications and the easy restoration of cathode material will reduce waste, demand for primary materials, and provide energy storage for less-demanding applications.

Reuse will typically involve downcycling —for example, using EV batteries for stationary storage. Meanwhile, restoration of battery components involves the refurbishment of battery packs—such as the replacement of depleted cathode material—without further processing.



Recycling and material recovery: extracting and processing of valuable raw materials from batteries is highly dependent on the chemistry of each battery. While emission-intensive pyrometallurgical recovery is the most well-developed form of battery recycling, hydrometallurgical and direct recycling methods have become a focus for research and development.

Incineration and Disposal: incineration involves the use of some battery material for fuel and disposal often involves the specialized long-term storage of the materials to prevent contamination. Nonetheless, improper disposal can lead to contamination, fires (as in primary-Lithium batteries), and high levels of material loss.