EverBESS: a tool for assessing the cost and environmental impacts of end-of-life management of battery energy storage systems

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Battery energy storage systems (BESSs) are pivotal in the decarbonization of the energy sector by enabling more extensive use of renewable energy technologies. From conventional lead-acid batteries to advanced flow-battery systems, BESSs span a wide range of chemistries and expected operational lifetimes. Thus, there are a variety of considerations at their end-of-life (EOL). Retrieving and reusing the materials and components used in BESSs is pivotal to advancing from the existing make-use-waste paradigm to a circular economy. Our work aims to build a user-friendly tool named EverBESS to assess the impacts of EOL management of various BESSs and design sustainable strategies to maximize material recovery and economic viability while minimizing environmental impact associated with decommissioning, logistics, and recycling.

Among BESSs, our work primarily focuses on three chemistries- lithium-ion batteries (LIBs), vanadium redox flow batteries (VRFBs), and sodium-ion batteries (SIBs) for the proactive design of EOL management strategies. LIBs account for over 90% of batteries used in BESSs, and their recycling is of paramount importance because they contain significant amounts of critical materials such as lithium, nickel, and cobalt. VRFBs are promising for long-duration energy storage. They present an EOL value from the large quantities of vanadium embodied which may potentially offset the cost of dismantling and recycling the BESS components post decommissioning. SIBs are increasingly being viewed as viable alternatives for LIBs as they decrease the U.S. dependence on critical materials, especially for large-scale energy storage. However, the absence of critical materials which often constitute an important revenue stream poses challenges to SIB recycling in terms of net costs. Here, we present a case study in which we use EverBESS to examine the cost and greenhouse gas emissions of EOL management of LIBs vs. VRFBs, identify major contributors and propose opportunities for improvement, and inform design-for-recycling and circular supply chain initiatives for BESSs. We also discuss existing knowledge gaps and our future research for sustainable EOL management of SIBs.