Techno-Economic Assessment of Artificial Intelligence-Enabled Sorting for Scalable Recycling of Spent Consumer Batteries in the United States

Dominic Aboagye, Hariteja Nandimandalam, Gamini P. Mendis*

School of Engineering, Penn State Behrend, Erie, Pennsylvania16563, United States

Abstract

The growing stream of spent consumer electronic batteries (e.g., alkaline, lithium-ion, NiMH, NiCd, small-sealed lead-acid) in the U.S. poses environmental risks like groundwater contamination and fire hazards, alongside economic challenges from rising battery demand and raw material supply risks. Effective end-of-life management is essential to recover critical materials. While automotive battery recycling (e.g., lead-acid) is well-established, consumer battery recycling is underexplored despite its hazardous waste impact and resource potential. Conventional recycling relies on inefficient, costly manual sorting due to diverse chemistries. Integrating AI for sorting could revolutionize recycling by improving efficiency, accuracy, and scalability, reducing costs and environmental impacts.

This study presents a preliminary techno-economic analysis of an AI-enabled sorting system developed by UHV Technologies for mixed consumer electronic batteries in the United States, benchmarked against manual sorting. The facility was modelled at 4,000 tons per year and assessed across three battery mix scenarios: SC1 (pessimistic), dominated by low-value primary chemistries; SC2 (base case), reflecting current U.S. collection data; and SC3 (optimistic), simulating a future stream rich in high-value Li-ion batteries. Revenues were derived from black mass containing Co, Ni, Li, and Mn, while expenses included transportation, capital costs, and operating costs, all scaled with throughput. Sorting efficiencies of 50–100% were tested across the three scenarios, with revenues, expenses, and net profits recalculated for each case. At 90% efficiency, AI-enabled sorting consistently outperformed manual methods by reducing OPEX and improving scalability. A multi-variable sensitivity analysis, performed in Python, evaluated uncertainties in black mass price (±20%), throughput (2,000–6,000 tons), transport distance (1,250–3,750 miles), and sorting efficiency (50–100%).

Results confirm the economic viability of AI-enabled sorting, with black mass price and annual throughput as the largest cost drivers. To our knowledge, this is the first U.S.-focused TEA comparing AI-enabled and manual sorting of mixed consumer batteries, providing a data-driven foundation to advance sustainable recycling infrastructure and support national critical material recovery goals.

Keywords: End-of-life treatment**;** Artificial intelligence**;** Techno-economic analysis; Sorting; Consumer electronic battery