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Prospects and Challenges of Lithium-Ion Battery Recycling Methods from Electric Vehicles In Vietnam

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ABSTRACT
The surge in global electric vehicle (EV) adoption poses significant challenges for managing end-of-life waste, especially lithium-ion batteries (LIBs). In Vietnam, a rapidly developing nation facing environmental concerns, effective LIB recycling is crucial. This paper evaluates the current status and potential of LIB recycling from EVs in Vietnam, highlighting limited research and adoption of modern recycling techniques. Pyrometallurgy and Hydrometallurgy methods are compared, with Pyrometallurgy offering simplicity and lower costs but less efficient metal recovery than Hydrometallurgy. Both methods require further refinement to suit Vietnam's context. Advancements in sorting technologies and standardized recycling processes are necessary. Collaborative efforts are essential for propelling Vietnam's LIB recycling sector toward sustainability and fostering economic opportunities in the EV ecosystem.
Keywords: *electric vehicles; lithium-ion batteries (LIBs), recycling.*

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I. INTRODUCTION

The rise of electric vehicles, fueled by the need to reduce carbon emissions and meet global environmental targets, is poised to revolutionize the automotive industry. In 2017, annual sales of electric vehicles surpassed one million units worldwide for the first time. Conservative estimates suggest that the waste generated by these vehicles, particularly from their battery packs, will reach significant levels as they reach the end of their life cycle. While current recycling efforts can mitigate some of this waste, the growing electric vehicle market presents substantial challenges in managing and disposing of this waste effectively. In recent decades, the significant rise of electric vehicles has exerted a profound impact on the energy and environmental sectors, particularly in Vietnam—a rapidly developing country grappling with severe air pollution and resource depletion. In this context, managing and recycling lithium-ion batteries from electric vehicles becomes a crucial factor in mitigating negative environmental impacts and optimizing resource utilization.

However, research on lithium-ion batteries (LIBs) recycling in Vietnam remains limited. Modern recycling methods and technologies have not been widely implemented, and the handling of used batteries often faces technical and environmental challenges. This underscores an urgent need for researchers and industries in Vietnam to focus on the development and adoption of advanced recycling processes.

This paper aims to assess the current status and potential of research and application of lithium-ion battery recycling from electric vehicles in the context of Vietnam. By synthesizing contemporary information and research, we hope this paper will contribute to expanding understanding and fostering the development of this field domestically.

Methods of Recycling and Applications in Vietnam

One of the most crucial methods in the lithium-ion battery recycling process is the chemical recycling process, where valuable materials can be extracted and reused. However, implementing this process requires investment in technology and infrastructure, which Vietnam currently lacks.

Furthermore, the development of recycling technology needs to be synchronized with waste treatment and other recycling processes in the industry to optimize efficiency and minimize environmental impact. This is particularly important in the context of Vietnam facing environmental pollution and ineffective waste management.

Despite numerous challenges that need to be overcome, the prospects for lithium-ion battery recycling in Vietnam are significant. The development of technology and international cooperation can help the country quickly catch up with global trends while creating business opportunities and sustainable development.

When lithium-ion batteries (LIBs) reach the end of their life cycle and are designated for recycling, three main processes are involved: stabilization, opening, and separation, which can be conducted individually or simultaneously. Stabilization of LIBs can be achieved through either brine or Ohmic discharge methods. Currently, in the industry, the preferred route for in-process stabilization during opening is adopted as it helps minimize costs. This process involves shredding or crushing the batteries within an inert gas environment, such as nitrogen, carbon dioxide, or a mixture of carbon dioxide and argon.

State-of-the-art physical processing techniques for LIBs in Europe and North America include the Recupyl (France), Akkuser (Finland), Duesenfeld (Germany), and Retriev (USA/Canada) processes. In large-scale European processes, stabilization techniques are not commonly used before breaking the cells open. Instead, they opt for opening them under an inert atmosphere of carbon dioxide or argon, with a minimal amount of molecular oxygen present (less than 4%). Opening the batteries under carbon dioxide allows for the formation of a passivating layer of lithium carbonate on any exposed lithium metal surfaces.

The Retriev process differs from the European methods in that it incorporates a water spray during the opening step. The water serves to hydrolyze any exposed lithium and acts as a heatsink, thereby preventing thermal runaway during the opening process.

Pyrometallurgical recovery

This method involves using a high-temperature furnace to reduce metal oxides from lithium-ion batteries to create an alloy of cobalt, copper, iron, and nickel. This process, similar to methods used for other battery types, is already established commercially for consumer lithium-ion batteries (LIBs). It's particularly advantageous for recycling general consumer LIBs, which are often unsorted, and can even include other types of waste, improving efficiency. This versatility also extends to electric-vehicle LIBs. The technique doesn't require a prior passivation step and can process whole cells or modules, with metal current collectors aiding the smelting process.

The pyrometallurgical process yields a metallic alloy fraction, slag, and gases. Gaseous byproducts contain volatile organics from the electrolyte and binder components, which decompose and burn off at higher temperatures. The metal alloy can be separated into component metals through hydrometallurgical processes, while the slag typically contains metals like aluminum, manganese, and lithium, suitable for further reclamation or alternative industrial uses. Safety risks are minimized as extreme temperatures and a reductant are employed, with hazards contained within the processing. While this method doesn't address reclaiming electrolytes, plastics, or lithium salts, and poses environmental concerns and high energy costs, it remains popular for extracting valuable transition metals like cobalt and nickel.

Physical materials separation involves various processes to separate recovered materials based on properties like particle size, density, ferromagnetism, and hydrophobicity. Techniques such as sieves, filters, magnets, shaker tables, and heavy media are used to separate lithium-rich solution, plastics, papers, casings, coated electrodes, and electrode powders. This results in fine fractions with concentrated electrode coatings and coarse fractions with plastics, casings, and metal foils. Coarse fractions undergo magnetic and density separation to remove materials like steel casings and separate plastics from foils. The fine product, known as the 'black mass', contains electrode coatings and carbon, which can be separated using froth flotation, exploiting the hydrophobicity of carbon. Various companies, including Recupyl (France) and Akkuser (Finland), utilize these processes for materials separation.

To liberate graphite and metal oxides from copper and aluminum current collectors in the 'black mass', various methods are employed. These include sonication in solvents like N-methyl-2-pyrrolidone (NMP) or dimethylformamide (DMF), thermal heat treatment, or dissolution of the aluminum current collector. However, these processes often require high temperatures (60–100 °C) and are relatively slow (3 hours). While ultrasound can speed up delamination (1.5 hours), it's still too slow for continuous-flow processing, and the required solvent-to-solid mass ratios of 10:1 are impractical on a commercial scale with these solvents.

Recent teardowns of cells show a shift away from fluorinated binders by manufacturers. Newer batteries are adopting alternative binders like carboxymethyl cellulose (CMC) for the anode and styrene butadiene rubber (SBR) for the cathode, which may be easier to remove at end-of-life. Water-based binder systems for cathodes are being explored, although they pose more challenges. Some studies have also investigated cellulose- and lignin-based binders, but many are still in the laboratory testing phase.

Hydrometallurgical methods involve using aqueous solutions to leach desired metals from cathode material, with the common combination of reagents being H_2SO_4/H_2O_2. Studies aim to optimize leaching efficiency by adjusting factors like acid concentration, time, temperature, solid-to-liquid ratio, and the addition of reducing agents, with H_2O_2 found to enhance efficiency by converting insoluble Co(III) to soluble Co(II). Other acids and reducing agents have also been explored. Leached solutions may undergo solvent extraction, followed by precipitation reactions to recover metals, typically extracting cobalt as sulfate, oxalate, hydroxide, or carbonate, and lithium through precipitation forming Li_2CO_3 or Li_3PO_4. Alternatively, mechanochemical treatment involves grinding electrode materials with chlorine compounds or complexing agents to produce water-soluble cobalt salts, which can be separated from insoluble fractions by washing with water.

Most recycling processes focus on reagent recovery, as materials with sufficient purity can be reused not only to resynthesize original cathode materials but also in various other applications, like synthesizing $CoFe_2O_4$ or $MnCo_2O_4$. Initial efforts centered on leaching and remanufacturing $LiCoO_2$, but now attention has shifted to new cell chemistries, often containing multiple transition metals (e.g., $LiNi1-x-yMnxCoyO_2$; NMC). After leaching metals from the cathode, sequential precipitation or direct remanufacture of the cathode is pursued. Some groups have proposed modifications such as additional solvent extraction steps or using lactic acid or urea as alternatives to sulfuric acid, while others investigate the impact of magnesium in resynthesized materials. Challenges include solvent volume, delamination speed, neutralization costs, and potential cross-contamination. The current cell design complicates recycling, particularly the mixing of anode and cathode materials, highlighting the need for improved material segregation methods. Despite efforts, current recycling methods still struggle to yield pure material streams for closed-loop battery systems.

In these two methods, Pyrometallurgy is the more common and less complex method, with lower costs compared to hydrometallurgy. However, the recovery of metals such as lithium is less efficient, and in some cases, aluminum cannot be recovered, resulting in poorer quality and quantity of recovered metals. Moreover, the energy consumption and recovery costs of Pyrometallurgy are higher than hydrometallurgy. On the other hand, hydrometallurgy has relatively good recovery capabilities for both types of metals. These are widely used methods globally and in Vietnam; however, they require further improvement to be suitable for developing countries like Vietnam.

Several improvements can make the electric vehicle LIB recycling process more economically efficient, such as better sorting technology, electrode material separation methods, more flexible processes, and standardized battery recycling and manufacturing. These improvements bring benefits in cost reduction, higher value of recovered materials, and almost eliminating the risk to labor.

Current battery packs have the drawback of being difficult to disassemble due to bonding methods and adhesive materials used. Therefore, all current commercial physical cell disintegration processes involve shredding or grinding followed by sorting of component materials. This makes component separation more challenging compared to pre-sorted materials, significantly reducing the economic value of the waste material stream.

II. CONCLUSION

The surge in electric vehicles (EVs) represents a pivotal shift in the automotive industry, driven by the imperative to mitigate carbon emissions and adhere to global environmental targets. As EV sales escalate globally, particularly in rapidly developing countries like Vietnam, the management and recycling of lithium-ion batteries (LIBs) emerge as critical components in mitigating adverse environmental effects and optimizing resource utilization.

Despite the burgeoning demand for EVs, research and implementation of LIB recycling in Vietnam remain nascent. The absence of widespread adoption of modern recycling techniques underscores the pressing need for Vietnam's researchers and industries to prioritize the development and integration of advanced recycling processes.

This paper has assessed the current landscape and potential of LIB recycling from EVs in Vietnam, aiming to catalyze domestic understanding and advancement in this field. By synthesizing contemporary research, we've identified significant challenges and opportunities, emphasizing the importance of synchronized technological development with waste management processes to minimize environmental impact.

Two primary recycling methods, Pyrometallurgy and Hydrometallurgy, present contrasting trade-offs in complexity, cost, and efficiency. While Pyrometallurgy offers simplicity and lower costs, Hydrometallurgy demonstrates superior metal recovery capabilities. However, both methods necessitate further refinement to align with Vietnam's developmental context and enhance economic viability.

Addressing current limitations in LIB recycling requires multifaceted approaches, including advancements in sorting technologies, electrode material separation methods, and standardized recycling processes. Moreover, streamlining disassembly processes for current battery packs is imperative to facilitate efficient recycling and maximize economic value from recovered materials.

Moving forward, concerted efforts from stakeholders across academia, industry, and government are essential to propel Vietnam's LIB recycling sector toward sustainability and resilience. By leveraging international cooperation and technological innovation, Vietnam can not only address its environmental challenges but also seize economic opportunities and foster sustainable development in the EV ecosystem.

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