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Reusing Lithium Batteries In Electric Vehicles: Potential And Challenges

Nguyen Thi Thanh Hoa
Thai Nguyen University of Technology
Email: Thanhhoadhktcn@tnut.edu.vn

ABSTRACT
As the electric vehicle (EV) industry continues to grow rapidly, the management of used Lithium-ion batteries (LIBs) becomes increasingly critical for ensuring sustainability and minimizing environmental impact. This paper explores the potential benefits and challenges of LIB reuse in EVs, along with strategies to optimize the reuse process. The study highlights the economic, environmental, and societal advantages of LIB reuse, including cost reduction in production, environmental impact reduction, and encouraging research and development. However, it also identifies significant technical challenges such as capacity loss, inconsistency in quality, and safety risks. To address these challenges, various reuse methods are proposed, including direct reuse, reuse after processing, component recycling, and secondary application reuse. Additionally, the economic viability of Battery-to-Use (B2U) is discussed, emphasizing the importance of factors such as cost, logistics, and second-use applications. Overall, by promoting innovative reuse methods, investing in research and development, and implementing supportive policies, the EV industry can optimize resource utilization, minimize environmental impact, and foster sustainability.
Keywords: *electric vehicles; lithium-ion batteries (LIBs), reuse.*

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I. Introduction

With a significant increase in the number of electric vehicles on the road and global commitments to reduce emissions, Lithium-ion batteries have rapidly become the cornerstone of the electric vehicle industry. With high efficiency and long lifespan, Lithium-ion batteries not only provide stable energy supply for electric vehicles but also promise a more sustainable and cleaner future for the transportation sector.

However, the remarkable growth of the electric vehicle market has created a new challenge: handling used batteries. With Lithium-ion batteries potentially losing around 20-30% of their capacity after several years of use, processing and reusing these batteries have become a major challenge for the industry. Nonetheless, seizing the opportunity of reusing Lithium-ion batteries can yield significant economic and environmental benefits for both manufacturers and consumers.

In this context, this paper will delve into the potential and challenges of reusing Lithium-ion batteries in electric vehicles, along with specific strategies and methods to optimize this process. Through further research and analysis on this issue, significant progress can be made in ensuring a sustainable and clean future for the electric vehicle industry.

The energy crisis and environmental concerns have spurred the rapid development of electric vehicles (EVs), a 63% increase from 2017. By 2040, EVs could make up 11–28% of global road transport fleets. Lithium-ion batteries (LIBs) are preferred for EVs due to their high energy density and reliability, lasting 8-10 years and 120,000 to 240,000 km. Disposal, recycling, and reuse are the main approaches for handling retired LIBs. Recycling can recover valuable materials, but challenges remain due to the variety of cathode materials. Reuse, prioritizing batteries with residual value, offers economic and environmental benefits. However, challenges persist in value estimation, life-cycle assessment, and safety management. This review outlines mainstream treatments of spent LIBs and comprehensively examines technical improvements and challenges in EV LIBs reuse, along with economic feasibility, supply chain, and regulatory hurdles, concluding with prospects for retired LIBs reuse.

II. Potential of Lithium-ion Battery Reuse

Reusing Lithium-ion batteries from used electric vehicles offers a range of economic, environmental, and societal benefits. In the context of the rapid growth of the electric vehicle market, battery reuse has become an indispensable part of the sustainable energy supply chain. Below are some key points regarding the potential of Lithium-ion battery reuse:

a. Cost Reduction in Production: Battery reuse helps minimize production costs compared to manufacturing new batteries. Reusing batteries provides a cost-effective and readily available source of raw materials for battery remanufacturing, thereby reducing pressure on resources and energy required for production.
b. Environmental Impact Reduction: Lithium-ion battery reuse contributes to reducing environmental impact compared to manufacturing new batteries and handling old batteries. By reusing already-produced energy sources, we mitigate the amount of waste and emissions polluting the environment.
c. Prolonging the Lifespan of Recycled Energy Sources: Although Lithium-ion batteries may lose some capacity over time, they can still provide stable energy sources for applications such as energy storage and auxiliary power systems. Reusing Lithium-ion batteries extends their lifespan and optimizes resource utilization.
d. Encouraging Research and Development: Lithium-ion battery reuse opens up opportunities for research and development of more advanced recycling technologies and processes. Enhanced research in this field can lead to advancements in battery technology, as well as improvements in reuse and recycling processes.
Overall, Lithium-ion battery reuse not only addresses our energy and environmental challenges but also serves as an opportunity to foster sustainable and innovative development in the industry. For manufacturers, researchers, and governments, investing in and promoting Lithium-ion battery reuse is a crucial step towards creating a green and sustainable future for the electric vehicle industry.

III. Technical Challenges

Although Lithium-ion battery reuse offers many benefits, it also faces significant technical challenges. These include issues related to performance, safety, and recyclability. Below are the main challenges encountered in the process of Lithium-ion battery reuse:
a. Capacity Loss: One of the major challenges in Lithium-ion battery reuse is capacity loss over time. Lithium-ion batteries can lose some of their capacity after several charge and discharge cycles, leading to reduced performance and battery life. Handling and reusing batteries with reduced capacity require complex methods and technologies to restore or enhance battery capacity.
b. Inconsistency in Quality: Lithium-ion batteries obtained from used electric vehicles often vary in quality. This may be due to differences in usage conditions, management, and battery maintenance. Inconsistency in quality can affect the performance and lifespan of batteries after reuse, especially in applications requiring high performance and reliability such as electric vehicles.
c. Safety Risks: Handling and reusing Lithium-ion batteries also pose safety risks. Lithium-ion batteries can cause explosion and fire if not handled properly. During the reuse process, strict safety procedures must be followed to ensure that batteries do not pose danger to the environment and humans.
d. Recycling Technology: Finally, another technical challenge is the development of efficient Lithium-ion battery recycling technology. Separating battery components, such as metals, electrodes, and electrolytes, and reusing them requires complex processes and technologies while ensuring the sustainability and energy efficiency of the process.
Overall, addressing the technical challenges of Lithium-ion battery reuse requires significant investment in research and technology development. However, with collaboration between manufacturers, researchers, and regulatory agencies, we can overcome these challenges and create an effective and sustainable Lithium-ion battery reuse process.
4. Lithium-ion Battery Reuse Strategy
To overcome technical challenges and optimize the Lithium-ion battery reuse process, it is necessary to develop appropriate methods and strategies. Below are some Lithium-ion battery reuse methods currently being implemented and researched:
Upon discontinuation of electric vehicle use, there are several options for used LIBs depending on their state-of-health (SOH) and remaining useful life (RUL). For LIB packs still operating at 70–80% of their initial capacity, they can be reused and repurposed in less demanding applications such as grid-connected or off-grid energy storage systems (ESS).
If packs fail to meet the 80% capacity requirement due to some cells being faulty while the rest of the pack is still functioning well, the faulty cells can be replaced, and the pack can be reused in EV applications after remanufacturing. This second-life battery (B2U) utilization is considered promising both economically and environmentally as the batteries can be used directly after passing necessary safety and performance checks without requiring any complex refurbishment processes or after disassembly and minimal remanufacturing. It is estimated that the B2U market could reach 26 GWh in 2025 and 1.01 TWh in 2063. The environmental advantage of B2U is underscored by the fact that producing new EV batteries can emit up to 16,000 kgCO2 equivalent, nearly half of the total.
In cases where battery packs fail to meet performance and safety requirements for direct reuse, they can be disassembled, undergo direct refurbishment processes to repair electrode materials and other components before returning to battery manufacturing and assembly.

Finally, heavily damaged end-of-life (EOL) battery packs can undergo recycling processes to recover valuable components such as lithium (Li), cobalt (Co), nickel (Ni), Cu, and Al. This review discusses three reuse pathways for used LIBs from electric vehicles:

a. Direct Reuse: The direct reuse method involves using Lithium-ion batteries from used electric vehicles without undergoing any processing or refurbishment. This is particularly common in applications such as auxiliary energy storage, where high performance is not the top priority, and cost is a significant factor.

b. Reuse after Processing: This method involves processing used Lithium-ion batteries to restore or enhance their capacity and performance before reuse. Processing methods may include regular charging for electrochemical balancing, replacing faulty components, and testing battery performance before reuse.

c. Component Recycling: Another reuse method is recycling Lithium-ion battery components, such as metals and electrolytes, for reuse in manufacturing new batteries or other applications. Recycling methods may include separation processes, melting, and chemical treatments to separate and clean components.

d. Secondary Application Reuse: Used Lithium-ion batteries can be reused for secondary applications such as backup energy storage, backup systems for personal electronics, and mobile applications. In these applications, high performance is not the primary factor, but using used Lithium-ion batteries can reduce costs and environmental impact compared to using new batteries.

e. Research and Development of Recycling Technology: Finally, an important part of the Lithium-ion battery reuse strategy is researching and developing new technologies to improve the reuse and recycling process. Research is focused on developing efficient recycling methods, improving the performance and lifespan of reused batteries, and minimizing environmental impact from processing used batteries.

After electric vehicle (EV) batteries are decommissioned, a series of steps are undertaken to ensure their stability, proper transportation, and evaluation before considering them for reuse in EVs or other applications. These steps encompass a comprehensive process of collection, inspection, evaluation, and sorting of battery packs and modules. However, predicting the aging behavior of spent lithium-ion batteries (LIBs) poses a significant challenge due to the multitude of factors influencing their state of health (SOH), including electrode and electrolyte compositions, driving patterns, operating temperatures, and charging procedures. Consequently, in-depth characterization becomes imperative, despite its time-consuming and costly nature.

Moreover, the incorporation of sophisticated sensors and information systems is essential to monitor battery utilization effectively, albeit at the expense of increased production costs. Evaluating the SOH and Remaining Useful Life (RUL) of LIBs requires a battery of tests, spanning physical, electrochemical, and spectroscopic techniques. While the ideal scenario involves testing battery modules without disassembling them to the cell level, this approach may not always be feasible. Instances arise where disassembly becomes necessary, particularly for LIB packs containing cells that fail to meet required performance and safety standards.

In this evaluation process, safety, remaining capacity, internal resistance, self-discharging rate, and cycle life are among the critical parameters assessed. Visual inspection serves as the initial step, aiming to detect visible damage such as bulging, deformation, or electrolyte leakage, which may render the battery unfit for reuse. Although visual inspection is relatively straightforward, it is labor-intensive and prone to human error. Consequently, efforts are underway to develop advanced image processing algorithms to automate this step, thereby enhancing efficiency and reliability.

Beyond visual inspection, historical operational parameters of LIBs are scrutinized, with specific criteria established to gauge their operational history. Subsequently, basic performance parameters are evaluated, encompassing cutoff discharge voltage, internal resistance, discharge capacities, and charge retention under varying conditions. Additionally, non-destructive computed tomography is employed to inspect the internal microstructure of LIBs, while anode analysis via 7Li magnetic resonance imaging identifies potential issues like Li dendrite formation.

Despite the effectiveness of these evaluation criteria in sorting spent LIBs for potential reuse or recycling (B2U), the absence of standardized protocols and regulations presents a significant challenge. The development of such protocols must prioritize universality, reliability, processing time, and cost-effectiveness. Furthermore, advancements in technologies for predicting SOH and RUL, as well as non-destructive safety testing processes, are imperative to facilitate the efficient and sustainable management of spent LIBs.

The economic viability of Battery-to-Use (B2U) hinges on factors like spent LIBs cost, logistics, storage, testing, second-use applications, and maintenance. Studies indicate that spent LIBs and labor costs dominate B2U's overall cost, with second-life LIB prices ranging from $25 to $250 per kWh. However, decreasing new battery prices may lower this range further, with projections suggesting a drop to below $60 kWh by 2030. Although debates persist about B2U profitability, certain applications like utility peaker plant replacement show promise. Despite some successful commercial products like Nissan's xStorage and "Mobi," most B2U remains at a pilot scale, requiring thorough economic evaluation before industrial deployment.

Additionally, B2U offers indirect benefits like reducing upfront EV costs by up to 25%, though this impact may diminish over time with decreasing new battery costs. While B2U holds potential in specific

stationary energy storage applications with environmental advantages, factors such as new LIB price reductions, lack of standardized testing procedures, and costly repurposing are critical determinants of its success. Therefore, strong political incentives and environmental policies are necessary to subsidize uncertainties and accelerate B2U adoption.
In conclusion, the diverse and innovative application of Lithium-ion battery reuse methods will optimize resource utilization and minimize environmental impact from the electric vehicle industry. Additionally, research and development of new technologies will create opportunities to advance further in the processing and reuse of Lithium-ion batteries, contributing to the sustainability of the industry and the living environment.

IV. CONCLUSION

In conclusion, the paper highlights the critical importance of addressing the challenges and opportunities surrounding the reuse of Lithium-ion batteries (LIBs) in the electric vehicle (EV) industry. With the rapid growth of EVs globally and the consequential increase in LIB usage, effective management of used batteries is imperative for ensuring sustainability and minimizing environmental impact.

The study underscores the potential economic, environmental, and societal benefits of LIB reuse, including cost reduction in production, environmental impact reduction, prolonging the lifespan of recycled energy sources, and encouraging research and development. However, it also identifies significant technical challenges such as capacity loss, inconsistency in quality, safety risks, and the need for efficient recycling technology.

To overcome these challenges, the paper suggests implementing various reuse methods, including direct reuse, reuse after processing, component recycling, and secondary application reuse. It also emphasizes the importance of research and development in recycling technology to enhance the reuse process further.

Moreover, the economic viability of Battery-to-Use (B2U) is discussed, highlighting factors influencing its success such as cost, logistics, storage, testing, and second-use applications. While B2U holds promise in specific applications, its widespread adoption requires political incentives, environmental policies, and standardized testing procedures.

In summary, by promoting innovative reuse methods, investing in research and development, and implementing supportive policies, the EV industry can optimize resource utilization, minimize environmental impact, and foster sustainability for future generations.

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