Office of Transport and Traffic Policy and Planning

From the People of Japan

Analysis of EV Battery End-of-Life

MINI REPORT

Supporting NDC Target through Incentivizing the Use of Electric Vehicles

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Executive Summary

This report provides a comprehensive review, analysis, and sets of recommendations for end-of-life management of batteries retired from electric vehicles (EV). The report covers the following key areas:

1. Key Trends and Challenges in Global Overview of the Volume of Batteries at their End-of-Life

- The demand for lithium-ion batteries, especially for EVs, is rapidly increasing. By 2030, global demand is projected to reach 4,700 GWh, with over 80% driven by the EV sector.
- By 2040, the volume of end-of-life lithium-ion batteries is expected to reach 20,500 kilotons, emphasizing the need for effective waste management strategies.
- The value chain for EV batteries includes raw material production, cell assembly, module assembly, and post-usage management. The end-of-life management process involves refurbishing, repurposing, and recycling batteries.
- The global recycling capacity for lithium-ion batteries is around 350,000 tons per year, with China leading the capacity due to its significant role in battery production and EV usage.
- Due to and increasing EV adaptation and supporting EV policy, projected battery waste in Thailand has been expected to reach 2.5 million tons by 2043.

2. Regional Regulations and Practices:

- The report provides an overview of global regulations and practices for managing end-of-life lithium-ion batteries, with a focus on Europe, the USA, China, and Japan.
- Approaches to battery waste management have not been globally unified with various approaches in different countries but nevertheless all are having common themes of commonality to electronic waste management, producer responsibility, and the development of efficient collection and tracking systems.

5. Status of Battery Management in Thailand:

- EV batteries are considered hazardous waste, requiring proper handling and disposal by licensed operators. Specific standards, like IEC62660 and UN ECE R100, apply to battery packs depending on the type of vehicle
- Thailand currently lacks specific laws dedicated to battery management, leading to varied disposal practices under existing regulations and increasing the risk of improper handling. The forthcoming 'Electric and Electronic Equipment Waste Management Act B.E. ...' is expected to address and regulate pathways for EV battery waste management."
- Five pathways for managing end-of-life EV batteries in Thailand were identified: EV batteries under warranty, EV batteries without warranty, Swappable or rental EV batteries, Post-accident EV batteries under insurance coverage, Post-accident EV batteries without insurance coverage each with varying risks of improper disposal.
- The absence of specific regulations leads to varied disposal practices, with a higher risk of improper management, particularly for batteries out of warranty or from accidents without insurance.
- New laws or regulations may be necessary to mitigate these risks and ensure the proper disposal and recycling of EV batteries in Thailand.

5. Challenges and Recommendations:

- Key Issues: Stakeholders across the battery value chain in Thailand have identified issues such as improper handling, high costs due to a lack of specific regulations, and import restrictions that hinder recycling efforts. Refurbished or repurposed battery pathways are challenging due to high costs, as used battery waste is taxed similarly to new batteries.
- Policy and Data Requirements: To address these issues, specific laws and regulations for battery management should be established, along with a national tracking system and standards for the storage and transportation of used batteries.
- Enhancing Value for Optimal Use: Clear standards for repurposing EV batteries and support for the development of a domestic battery repurposing and recycling industry through incentives should be considered.
- Promoting the Recycling Industry: The report suggests permitting the importation of used batteries and reducing or exempting taxes to ensure sufficient volume for cost-effective recycling, along with supporting related industries in the value chain..

In summary, there is an urgent need for a consistent framework for end-of-life battery management and the development of a recycling industry in Thailand. This framework is crucial for ensuring safety, enhancing environmental protection, and supporting the sustainable growth of the EV sector.

Acknowledgement and Cradits

This report is primarily based on the white paper titled “Situation, Issues, and Recommendations for End of Life Battery Management,” published in April 2024 by the Thailand Energy Storage Technology Association (TESTA). The principal authors are Nattanai Kunanusont, a researcher, and Pimpa Limthongkul, Principal Researcher at the Energy Storage Technology Research Team, National Energy Technology Center, under the National Science and Technology Development Agency (NSTDA) in Thailand.

Valuable insights on the current situation and future directions were contributed by TESTA members, including Kornwika Chaiprateep, Dr. Vitchaphol Motaneeyachart, Prof. Chanathip Pharino, Dr. Aksornchan Chaianong, and Dr. Rattiporn Munprom.

Additional information on end-of-life battery pathways was provided by BMW (Thailand), PEC Technology (Thailand), Amita Technology (Thailand), TUV SUD (Thailand), Waste Management Siam, SK TES (Thailand), Thonburi Energy Storage Manufacturing, Umicore Precious Metals (Thailand), Nuovo Plus, Beta Energy Solution, Thai Honda, SAIC Motor-CP, Oska Holding, Life’s Moving, ETRAN (Thailand), Toyota Tsucho (Thailand). Supports regarding regulations and Thai policy were generously provided by the Department of Industrial Work, Ministry of Industry, the Center of Excellence on Hazardous Substance Management (HSM) at Chulalongkorn University, and the Excise tax department.

This work was made possible with the support of the United Nations Development Programme (UNDP).

1

Global Battery Landscape

The rapid advancement and adoption of electric vehicles (EVs) have led to a significant increase in the demand for lithium-ion batteries, which are the primary energy storage solution for these vehicles. As the global shift towards electric mobility intensifies, understanding the trends and challenges associated with EV battery production, usage, and end-of-life management becomes crucial. This chapter delves into the global trends in EV's lithium-ion battery usage, highlighting the substantial growth in demand driven primarily by the electric vehicle industry. With projections indicating a steep rise in both battery production and the volume of end-of-life batteries in the coming decades, the chapter introduce global strategies for managing this surge in battery waste.

1.1 Global Trend in Battery for EV

It is well known that lithium-ion batteries are currently widely used as energy storage sources globally. They are utilized in portable electronic devices, stationary energy storage systems, and electric vehicles (EVs). According to the usage data shown in Figure 1 , the global demand for lithium-ion batteries was approximately 700 GWh in 2022 and is projected to increase by 27% annually, reaching 4,700 GWh by 2030. China has the highest demand compared to other countries. Furthermore, when breaking down the demand by application, it is evident that over 80% of the lithium-ion batteries comes electric vehicles (Mobility). This implies that in the future, the majority of end-of-life batteries will be originated from usage in the transportation sector. [1]

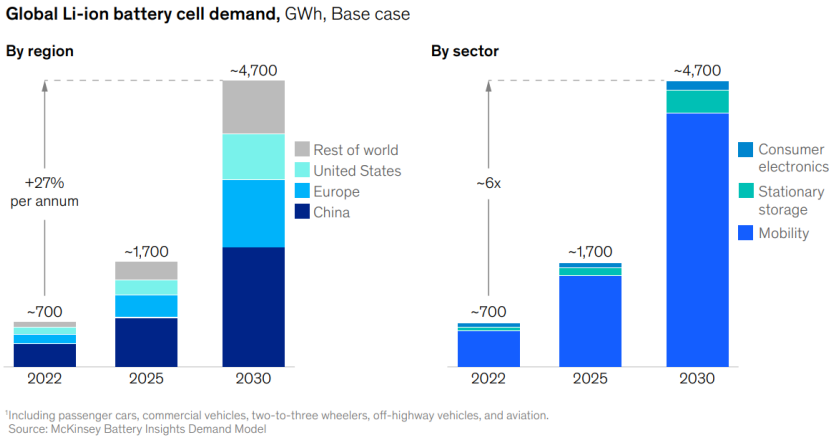

Figure 1 Battery Usage Volume by Region and by Application Type [1]

According to the projections of end-of-life battery volumes from usage and production, as shown in Figure 2, it is evident that the global volume of end-of-life lithium-ion batteries will be only 900 kilotons in 2025. This relatively low volume is due to the fact that end-of-life batteries from electric vehicles are not yet significant. However, with the increasing usage of lithium-ion batteries, the volume of end-of-life batteries is expected to increase by an average of 25% annually, potentially reaching 20,500 kilotons by 2040. This represents a substantial amount of waste, with approximately 94% coming from usage and around 6% from production scrap [2]. Therefore, it is crucial to be prepared for the management of end-of-life batteries to accommodate the future volume of lithium-ion battery waste.

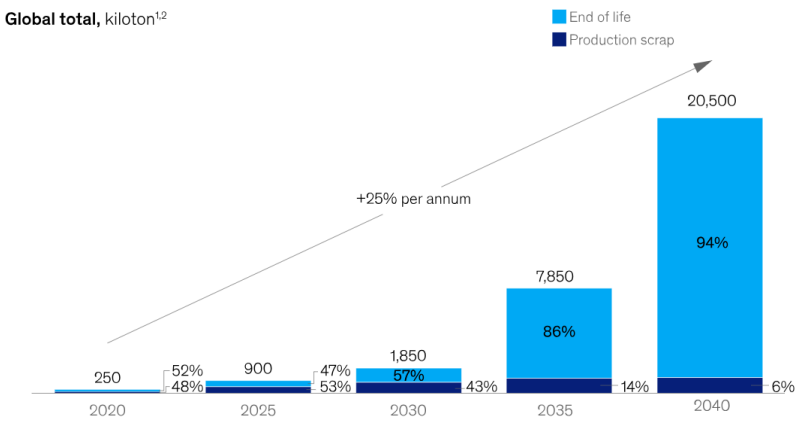

Figure 2 Projected Volume of End-of-Life Batteries from Usage and Production Scrap Worldwide [2]

1.2 EV Battery Value Chain

The production, usage, and management of electric vehicle batteries involve various stakeholders across multiple sectors. From the value chain of electric vehicle batteries shown in Figure 3, the value chain begins with the raw material production process, followed by the battery cell assembly process, the module and battery pack assembly process, and the usage of batteries in various forms. After the batteries degrade post-usage, they enter the waste stream. This starts with the collection and storage of end-of-life batteries, which are then evaluated to determine the suitable management pathway.

If the EV battery modules are still functional for use in electric vehicles (EVs) but have some damaged electronic components, they will be sent for refurbishment (also known as remanufacturing) to restore the faulty parts. Once refurbished, these EV batteries will undergo testing and then will be reinstalled in EVs. If the EV modules are no longer suitable for EV applications but can be used in energy storage systems (ESS), the batteries will be redesigned and reassembled into new battery packs. In this case, the battery management system (BMS) must also be reconfigured to suit the new application. The repurposed packs will then be tested and installed as ESS. However, if it is determined that the EV battery modules cannot be re-used in any application, they will be sent for recycling. The recycling process can be divided into three main methods: pyrometallurgy, hydrometallurgy, and direct recycling. Details of each process will be explained in the next section.

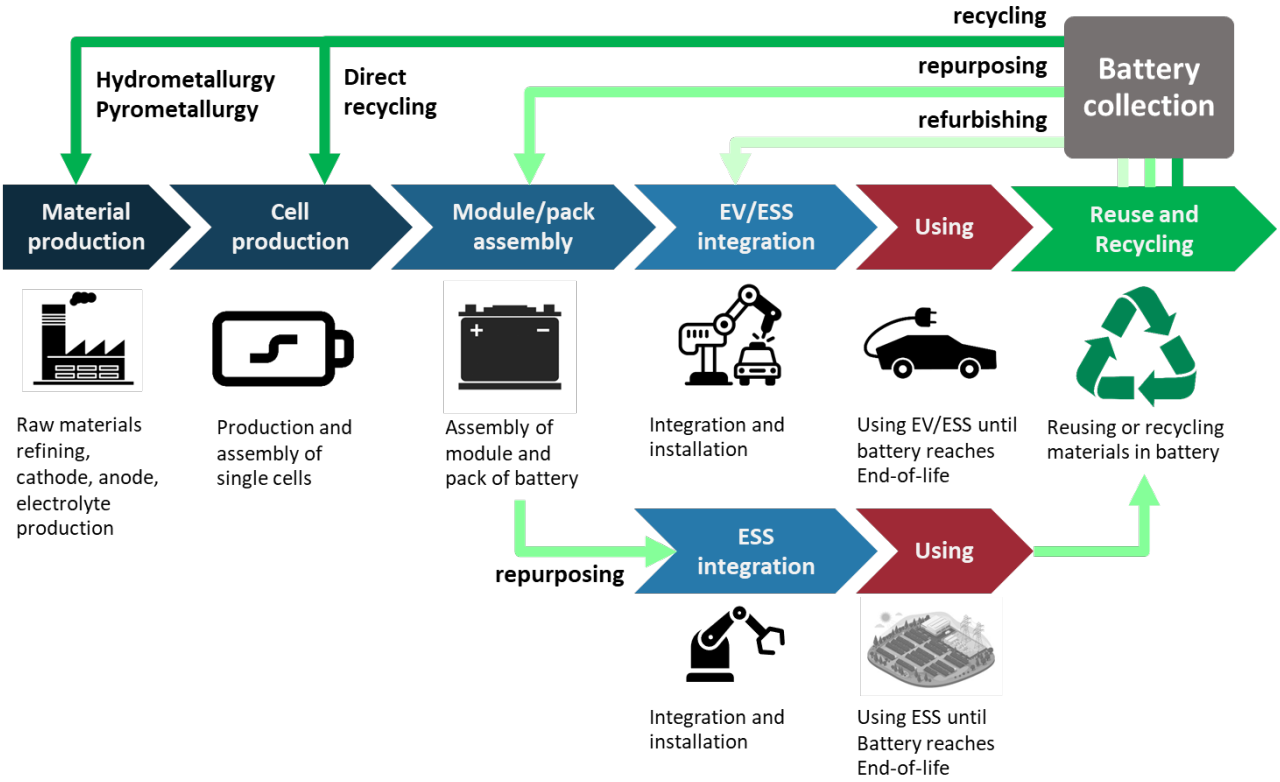

Figure 3 flow of EV batteries value chain

The global demand for lithium-ion batteries is rising significantly, leading to substantial growth in business opportunities related to the battery value chain. It is projected that the global business opportunities for lithium-ion batteries will reach $302 billion USD by 2030, an increase of more than eight times compared to 2018, as shown in Figure 4 [3]. Most of these business opportunities lie in the production of lithium-ion battery cells, with China holding the largest share in this sector. Revenue opportunities from the reuse and recycling of lithium-ion batteries are expected to account for 4% of the total lithium-ion battery business by 2030.

Figure 7: Battery value chain opportunities of $300 billion in 2030

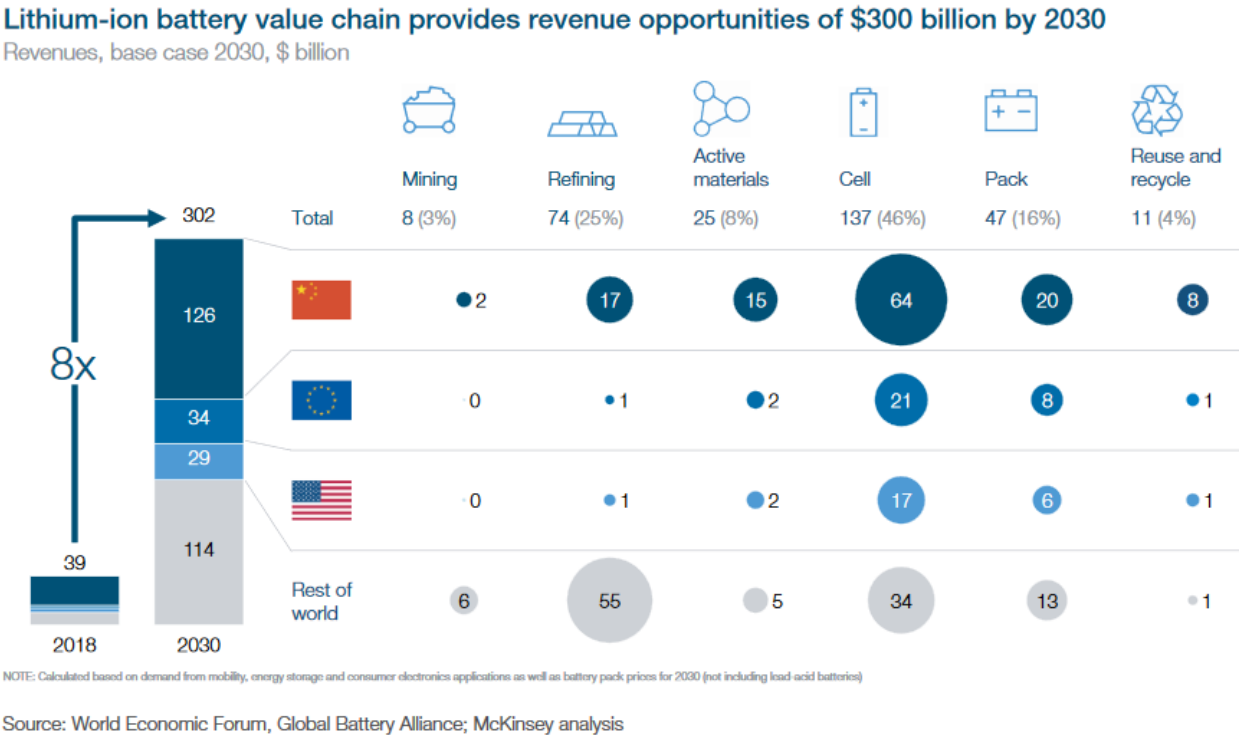

Figure 4 revenue of Li-ion battery value chain by 2030 [3]

1.3 End of Life Battery Handling Pathway

1.3.1 Refurbishing

Refurbishing involves taking end-of-life batteries, repairing the damaged parts, and returning them to their original use. The degradation of these batteries may not necessarily occur at the cell level but could be due to issues such as wiring damage, battery management system (BMS) failure, case damage, or damage to a specific module within the battery. These batteries are recalled, and only the damaged parts are repaired or replaced. The refurbished battery packs are then returned to their original application.

1.3.2 Repurposing

Repurposing involves taking end-of-life batteries and modifying them for use in different applications. This process starts with designing the battery pack for its new application, as the requirements for the new use differ from the original. After designing the new battery pack, the end-of-life battery packs undergo inspection and sorting as shown in Figure 4 [4].

The inspection and sorting process begins with assessing the electrical performance and physical damage of the battery pack. If the pack passes the inspection, it can be repurposed as a whole pack. If the pack fails the inspection, it is disassembled to the module level. Each module's electrical performance is then tested. Modules that pass the inspection are used to assemble new battery packs for repurposing. Modules that do not pass the inspection are further disassembled to the cell level. Each battery cell is then tested and sorted based on performance. Cells that pass the inspection are used to create new battery modules. Cells that fail the inspection are sent for recycling to recover valuable materials.

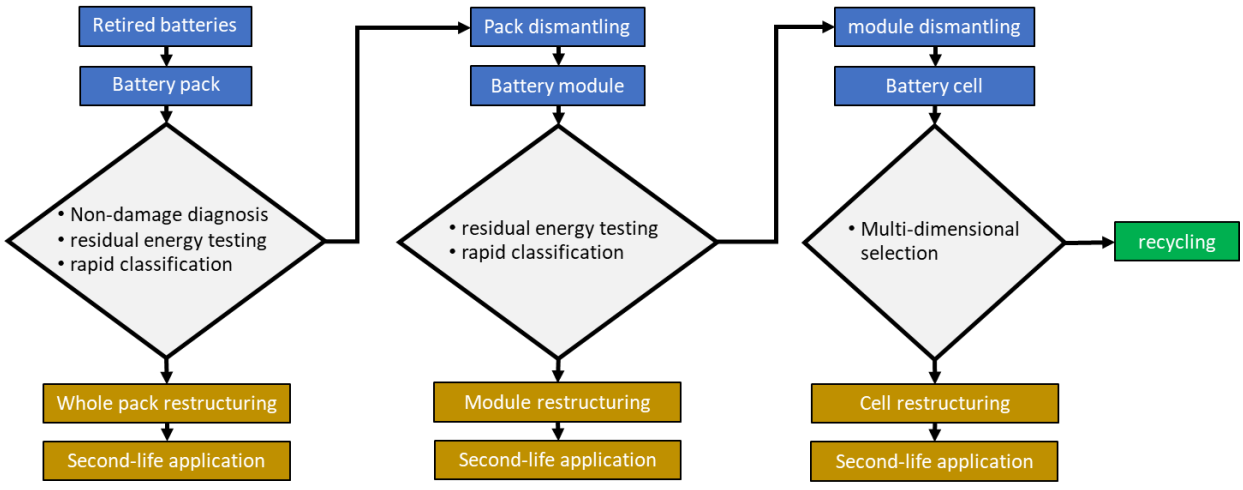

Figure 5 Evaluation process of EV batteries restructuring for second-life applications [4]

For repurposed battery packs, after the re-assembly, they must be tested for safety according to standards. Currently, international safety standards for repurposed battery packs include,

- **IEC 63330-1:2024** Repurposing of secondary batteries - Part 1: General requirements. This standard covers data on primary usage, data for designing repurposed products, and methods for designing repurposed battery packs.
- **UL 1974: 2023** Evaluation for repurposed batteries. This standard includes processes for re-purposing batteries such as initial inspection of battery packs, proper disassembly and storage of battery packs, testing of battery cells and other components, sorting battery cells based on physical damage and performance, assembling battery packs for new applications, and testing the performance and safety of the newly assembled battery packs.
- **GB/T 34015-2017** Recycling of Traction Battery Used in Electric Vehicle – Test of Residual Capacity
- **GB/T 34015.2-2020** Recycling of Traction Battery Used in Electric Vehicle – Echelon Use – Part 2: Removing Requirements
- **GB/T 34015.3-2021** Recovery of Traction Battery Used in Electric Vehicle – Echelon use – Part 3: Echelon Using Requirement
- **GB/T 34015.4-2021** Recovery of Traction Battery Used in Electric Vehicle – Echelon use – Part 4: Labels for Echelon Used Battery Products

Repurposed battery packs are generally used in applications with lower demand than their original use. For example, a battery pack from a degraded electric vehicle, after being refurbished, might be used in stationary energy storage systems. These systems typically do not operate continuously throughout the day and do not require high electrical currents, which helps extend the lifespan of the repurposed battery pack.

Several companies and organizations have initiated projects to repurpose used electric vehicle (EV) batteries for second-life applications, particularly in energy storage systems (ESS). Here are a few notable examples:

1. **Bosch BMW Vattenfall project:** The Swedish power company Vattenfall has been involved in repurposing EV batteries for large-scale energy storage projects. One example is their project in collaboration with BMW, where used BMW i3 batteries were repurposed to create a large energy storage system at the Hamburg, Germany, with the installed capacity around 2 MWh. This project stores energy from both the grid and solar panels, providing backup power and helping to balance the grid.
2. **Nanyang City project:** This project applied reused EV batteries from retired BYD E6 Taxis and installed as energy storage connected with State Grid Nanyang Power Supply Company in 2019. The installed capacity was around 1 MWh
3. **xStorage by Nissan:** Nissan, through its 4R Energy Corporation joint venture with Sumitomo Corporation, has been repurposing used Nissan LEAF batteries. These repurposed batteries are used in various applications, including residential and commercial energy storage systems, as well as in smaller-scale projects like powering streetlights.
4. **TEPCO-Toyota Pilot project:** TEPCO (Tokyo Electric Power Company) has been collaborating with Toyota to develop a pilot project utilizing second-life batteries from retired Toyota hybrid electric vehicles (HEVs). These repurposed batteries are being used as energy storage at the Eurus Tashirotai Wind Farm in Japan, with an installed capacity of around 3 MWh (providing 1 MW of output from the repurposed batteries). In this project, both TEPCO and Toyota are responsible for providing information to develop safety standards for repurposed EV batteries.

1.3.3 Recycling

The recycling process involves extracting materials from used batteries and processing them to reclaim valuable substances. These reclaimed materials can be used as raw materials for producing new batteries or other products. The details of the recycling process and how reclaimed materials are reintegrated into the battery production value chain are shown in Figure 6 [5]. After batteries degrade, they are collected and sent for material separation before undergoing the recycling process. The material separation process typically starts with stabilizing the batteries by discharging them, which can be done by immersing them in an ionized solution, such as saline water. Next, the batteries are disassembled and reduced in size. The fragmented materials are then physically separated based on their properties, such as size, density, and magnetism. After this, the materials undergo purification before entering the recycling process. The battery recycling process can be divided into three main methods [6], which are

- **Pyrometallurgical Process** This method involves smelting the materials at high temperatures. The outcome of this process is an alloy and slag.
- **Hydrometallurgical Process** This method involves leaching the materials using chemicals such as acids or bases to dissolve valuable metals. The result of this process is metal salts, which can be used as raw materials for producing new battery materials.
- **Direct Recycling Process** This method involves taking degraded materials and repairing their structure and chemical composition to restore their performance and properties to a level comparable to new battery materials. These repaired materials are then used as components for new battery cells.

The advantages and disadvantages of each recycling process are summarized in Table 1. The pyrometallurgical process, which has been used for a long time in metal recycling, has the advantage of being straightforward and not requiring hazardous chemicals. However, it requires high thermal energy. The hydrometallurgical process yields highly pure products and does not require high thermal energy, but it uses hazardous chemicals that can impact the environment. The direct recycling process has the advantage of low energy consumption and does not use hazardous chemicals, resulting in lower process costs. However, its efficiency depends on the degradation and purity of the materials being recycled, which is why it is still under development and not yet widely used at the industrial level.

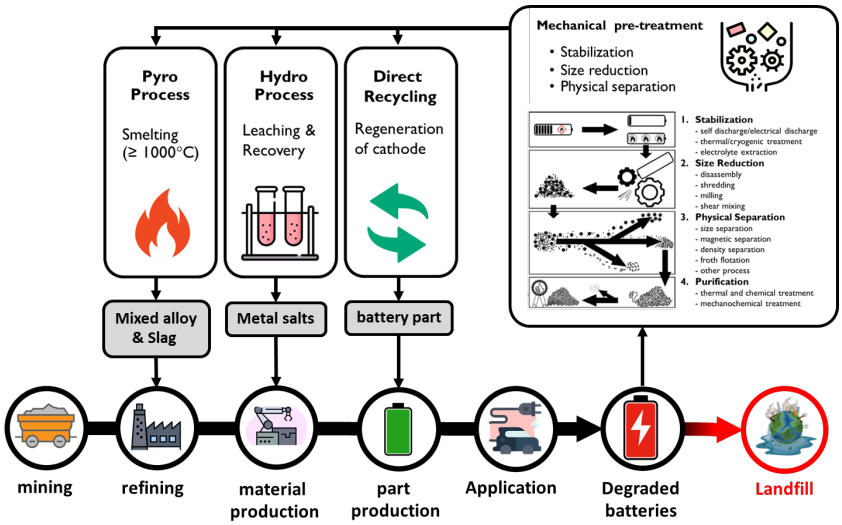

Figure 6 Battery Separation and Recycling Process [5]

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Table 1 Types of Processes, Outputs, Advantages, and Disadvantages of Battery Recycling Methods

Countries	Pyrometallurgy	Hydrometallurgy	Direct recycling
Process	• Smelting	• Leaching • recovery	• Re-lithiation • Heat treatment
Outputs	• Alloy • Li, Al in slag	• Alloy • Metal salts (sulfates, carbonates, hydroxides etc.)	• Cathode active materials
Advantages	• No size reduction required • Low complexity • Reliable technology due to long-term development	• Low energy consumption • Applicable to various types of batteries • High purity of outputs	• Low energy consumption • No need for large quantities • Low cost • Low greenhouse gas emissions
Disadvantages	• Li and Al are mixed in the slag • Requires separation process using hydrometallurgy • Economically viable only in large quantities	• Requires size reduction • Uses acids, which are not environmentally friendly • Complex process	• Variability in effectiveness based on the degradation level of battery materials • Not yet feasible for industrial-scale implementation

Currently, there are industrial facilities worldwide that operate lithium-ion battery recycling. The distribution and recycling capacity of these facilities in different countries are shown in Figure 7[8] Overall, the global recycling capacity for batteries is approximately 350,000 tons per year. China has the highest recycling capacity, reaching 188,000 tons per year, which accounts for about 50% of the global battery recycling capacity. This is because China is the largest producer of lithium-ion batteries with the highest sales of electric vehicles, leading to an increase in recycling facilities to support this demand.

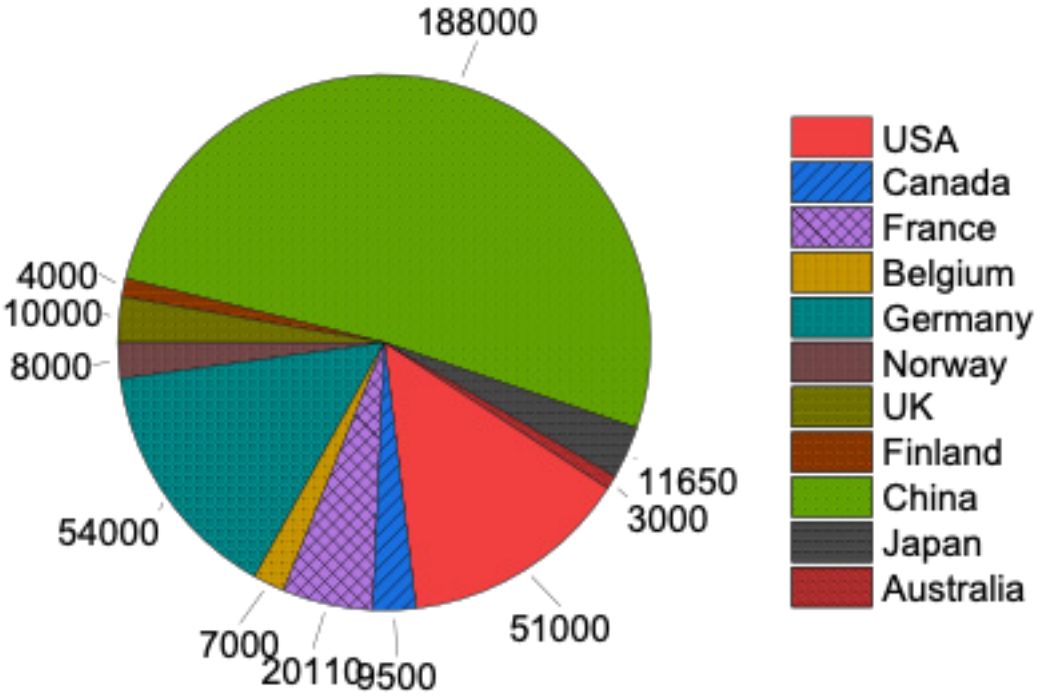
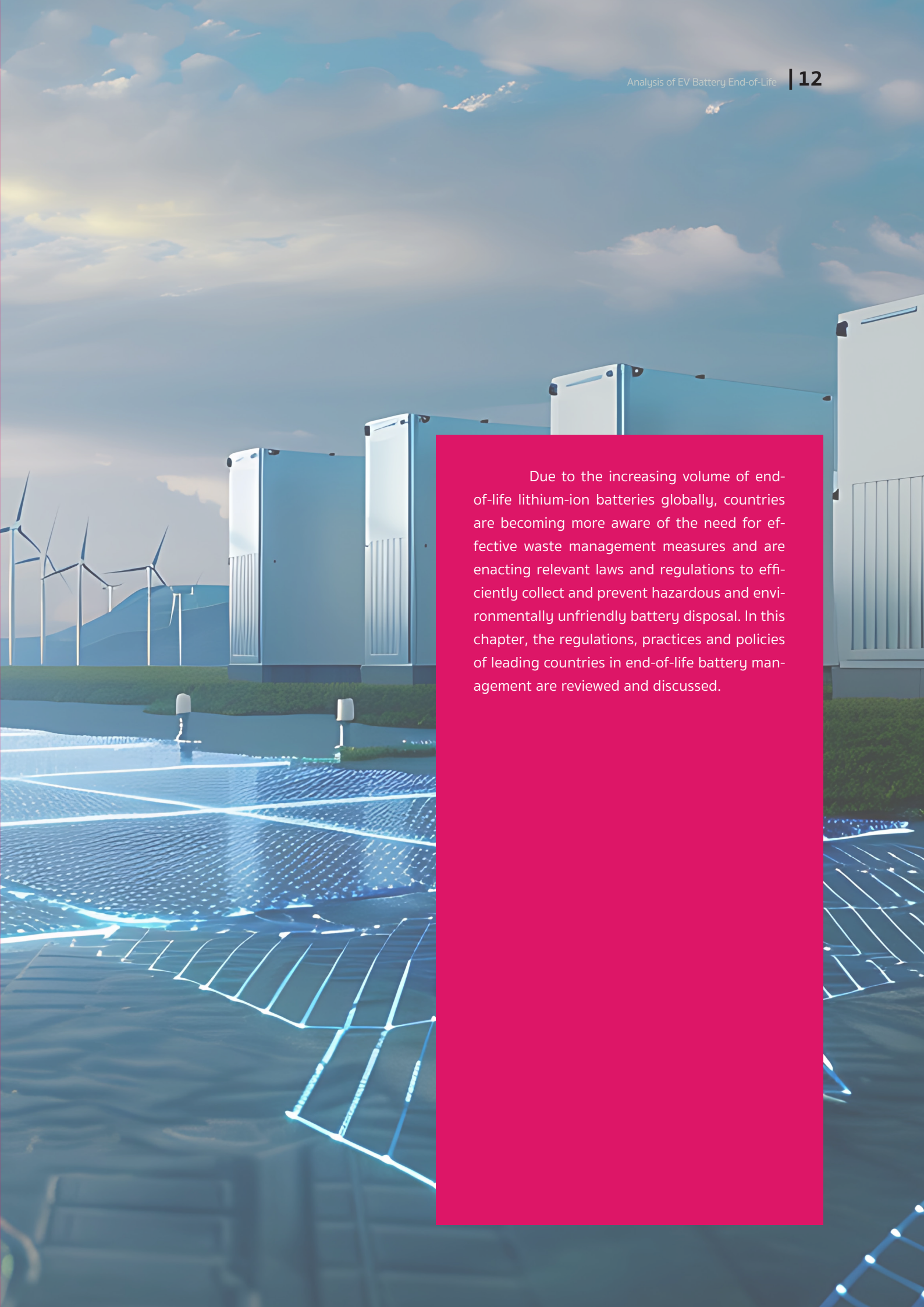


Figure 7 Battery Recycling Capacity by Country (units: tons/year) [8]

2

End of Life Battery Management: Regulations and Practices (Global)



Due to the increasing volume of end-of-life lithium-ion batteries globally, countries are becoming more aware of the need for effective waste management measures and are enacting relevant laws and regulations to efficiently collect and prevent hazardous and environmentally unfriendly battery disposal. In this chapter, the regulations, practices and policies of leading countries in end-of-life battery management are reviewed and discussed.

2.1 Europe

The European Union is a leading group in terms of battery regulation and management systems. It began with the implementation of the Waste Electrical and Electronic Equipment Directive (WEEE Directive 2006/66/EC) in 2006. In 2023, the EU introduced "regulation (EU) 2023/1542", which is a comprehensive piece of legislation adopted by the European Union (EU) that focuses on the sustainability, circularity, and overall lifecycle management of batteries. This regulation replaces the previous Battery Directive (2006/66/EC) and aims to address the environmental, social, and economic impacts of batteries throughout their entire lifecycle—from design and production to reuse, recycling, and disposal [9]. The regulation covers all types of batteries placed on the EU market, including portable batteries, automotive batteries, electric vehicle (EV) batteries, and industrial batteries. It applies to manufacturers, importers, distributors, and recyclers, ensuring that they adhere to strict standards and requirements throughout the battery lifecycle. The regulation also provides information on sustainability and safety requirements.

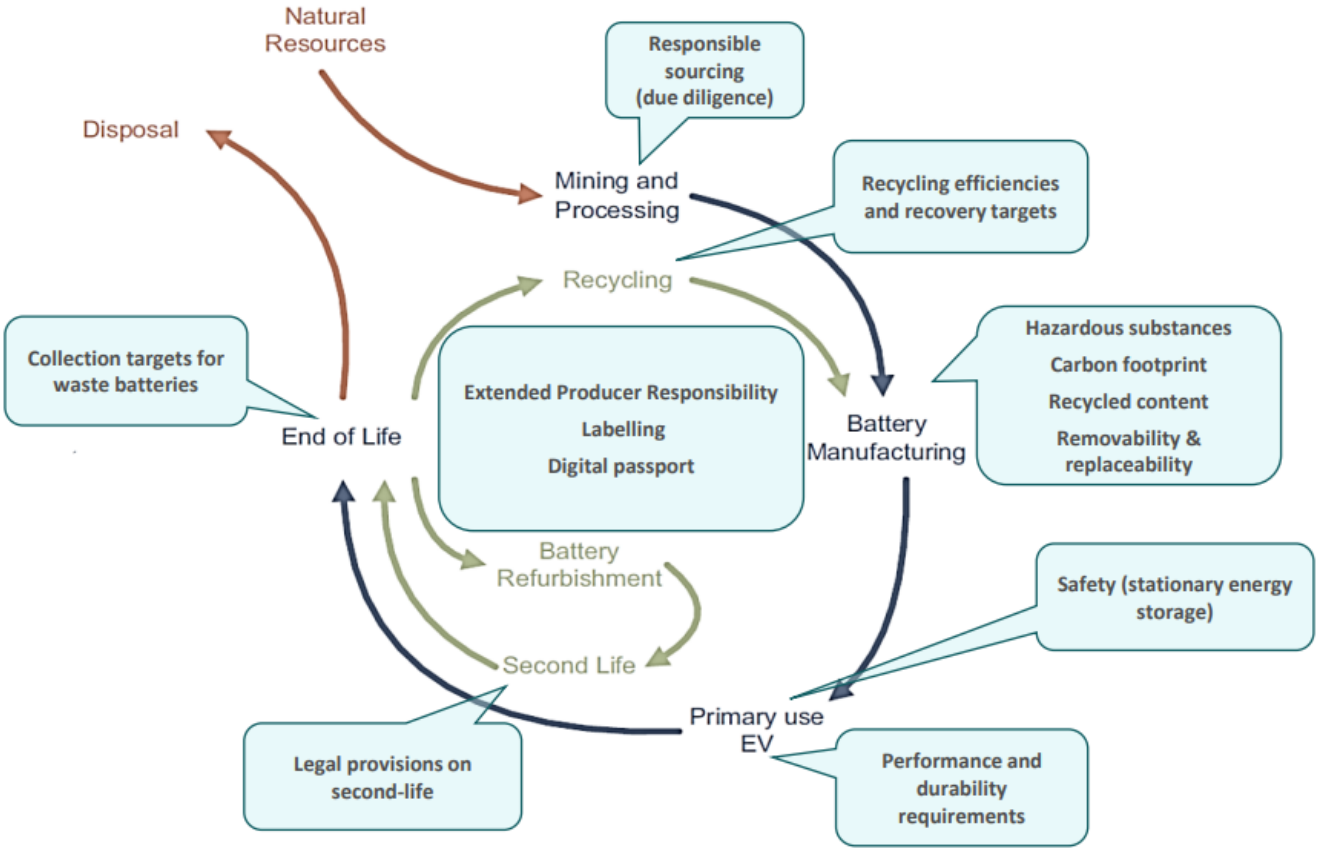


Figure 8 Concept of EU battery passport applied through whole battery value chain [9].

The regulation sets out specific requirements for the design, performance, and safety of batteries. This includes mandatory levels of energy efficiency, durability, and reliability. It introduces minimum recycled content requirements for key raw materials used in battery production, such as cobalt, lead, lithium, and nickel, promoting the use of recycled materials to reduce dependency on primary raw materials. It also implements labeling and information, where batteries must be labeled with relevant information, including their carbon footprint, recycled content, and performance characteristics, allowing consumers to make informed choices. In terms of life cycle management, producers are required to take responsibility for the entire lifecycle of batteries, including their collection, treatment, and recycling after use. This responsibility extends to ensuring that batteries are collected and recycled at the end of their life. The regulation sets ambitious collection targets for waste batteries, with specific goals for different types of batteries. For example, it mandates higher collection rates for portable batteries and sets specific targets for the collection of industrial and EV batteries.

The regulation establishes high recycling efficiency targets for key battery materials, ensuring that valuable materials are recovered and reused in new batteries or other applications. It encourages the reuse and repurposing of batteries, particularly EV batteries, for secondary applications such as energy storage systems. This helps extend the life of batteries and contributes to a circular economy. Additionally, the regulation introduces the “digital battery passport,” a digital tool that records crucial information about batteries, including their composition, performance, and life-cycle history. This passport system enhances the tracking of batteries from production through end-of-life, improving recycling and reuse processes. Starting in 2027, this digital battery passport will be mandatory for all batteries with a capacity greater than 2 kWh.

2.2 USA

The United States is another country with high electric vehicle usage. There are guidance on end of life handling by U.S. Environmental Protection Agency (EPA). However, there are no federal laws specifically governing battery management; instead the regulations of battery waste are governed by or combined with electronics or hazardous waste. And regulations vary by state [10]. Examples of the regulations/ laws of the different states are provided here:

- **California Cell Recycling Act:** Enhances the state's system for the collection, recycling, and management of batteries in California.
- **New York Rechargeable Cell Law:** Requires sellers of batteries to accept and dispose of used batteries.
- **Vermont Main Single-Use Cell Law (Act 139):** Prohibits the landfilling of nickel-cadmium batteries or lead-acid batteries.

2.3 China

China is one of the countries with specific laws and regulations for managing electric vehicle (EV) batteries. Given the high production and use of EV batteries in China, there is a significant increase in domestic battery waste. China has begun reviewing its legislation to include Extended Producer Responsibility (EPR) systems for collecting EV batteries, mandating that battery manufacturers are responsible for collecting the waste either directly or through partnerships with other entities.

Additionally, there is a push to develop networks for collecting end-of-life batteries. EV battery manufacturers are encouraged to establish battery codes and tracking systems for their batteries. The Ministry of Industry and Information Technology (MIIT) of China has issued policies requiring EV battery manufacturers to create collection channels, encouraging cooperation among battery manufacturers, vehicle manufacturers, waste collection and dismantling operators to develop diverse collection routes. The policy also supports easier recall of end-of-life EV batteries by establishing a national traceability platform where battery usage can be registered. Under this system, battery manufacturers must create and affix producer codes on EV batteries or batteries intended for reuse, repurposing, or second life. Subsequently, EV manufacturers, battery sorting operators, and recycling operators are responsible for managing and tracking these batteries using the system, including updating usage or management information within the platform. [4]

2.4 Japan

Regarding the regulations or laws for managing lithium-ion battery waste in Japan, there are currently no specific regulations or laws in place. However, other laws can be applied to the management of lithium-ion battery waste, such as the Automobile Recycling Law (2012). This law supports the recycling of electronic equipment and assigns responsibility for battery recycling to manufacturers, distributors, consumers, organizations, and service providers.

Additionally, the Japan Auto Recycling Partnership (JARP) has been established as a network that serves as an intermediary for collecting lithium-ion batteries from electric vehicles and integrating them into the recycling system. The network consists of 12 locations nationwide, primarily made up of automotive companies aiming to collect battery waste for recycling. The focus of recycling efforts is mainly on nickel-metal hydride (Ni-MH) batteries, as they are widely used in hybrid electric vehicles in Japan.

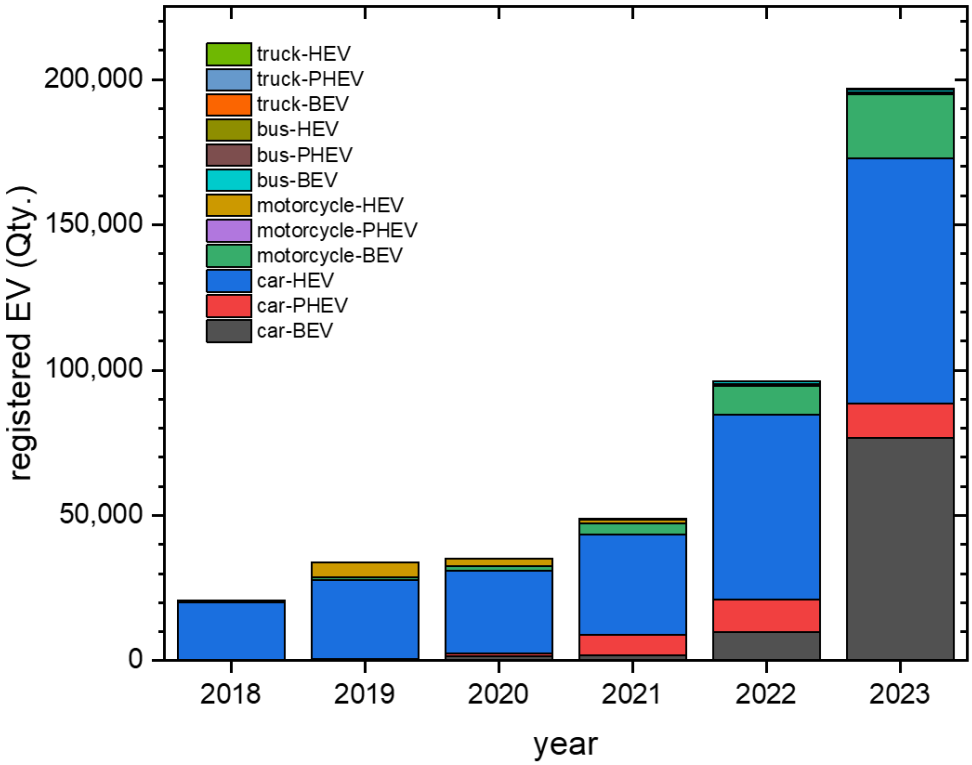
3

End of Life Battery Management Regulations and Practices: Current Status (Thailand)

Battery usage in Thailand aligns closely with global trends, particularly in the growing adoption of electric vehicles (EVs). This chapter provides a comprehensive review of the trends in EV adoption within Thailand, along with projections for future EV battery waste. It also examines the regulatory framework governing EV battery management in the country. The current lifecycle of EV batteries, from production to end-of-life, is discussed in detail, highlighting the processes and challenges involved. Based on these insights, recommendations for enhancing EV battery recycling policies in Thailand are proposed, aiming to address the anticipated increase in battery waste and improve sustainability in the EV sector.

3.1 Trend on EV adaptation in Thailand

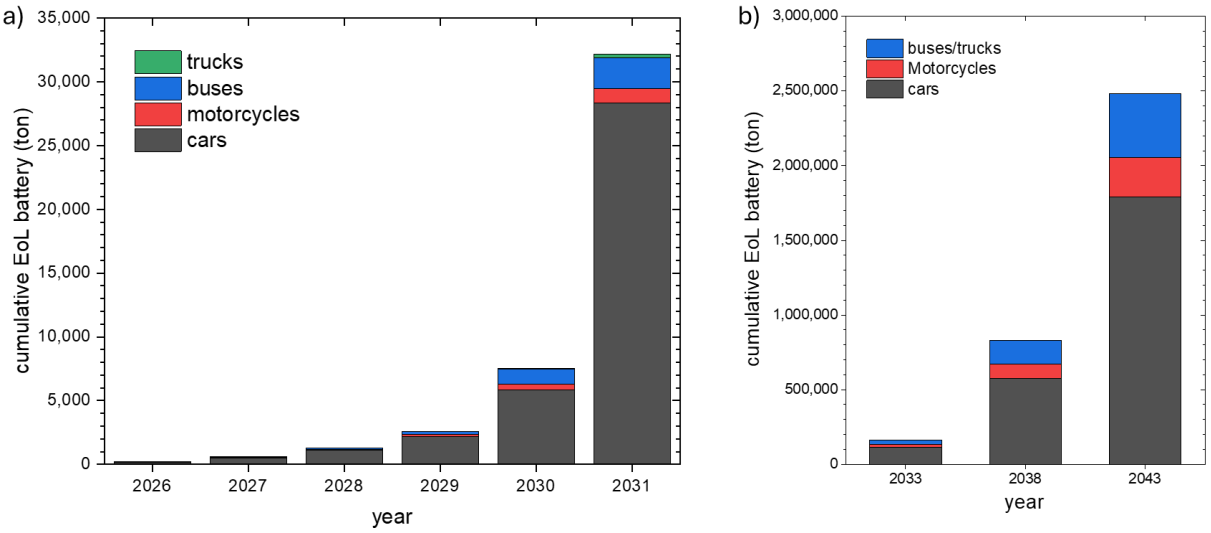
According to data from the Land Transport Statistics Group, Planning Division, Department of Land Transport, the usage volume of electric vehicles can be categorized by vehicle type (personal cars, motorcycles, buses, trucks) and battery type (HEV, PHEV, and BEV), as shown in Figure 9. It is evident that the number of registered electric vehicles in Thailand has increased significantly. In 2018, most registered electric vehicles were personal cars of the HEV type. However, in 2022 and 2023, the number of registered personal BEVs increased substantially, reaching approximately 40% of all registered electric vehicles. This indicates that in the future, registered electric vehicles in Thailand will predominantly be personal BEVs, which use lithium-ion batteries. Additionally, in 2023, the total number of registered electric vehicles reached nearly 200,000, doubling the total number registered in 2022, with a trend of continued growth in the coming years.



หมายเหตุ: รถยนต์ (car) ได้แก่ รย. 1 ถึง 11, รถมอเตอร์ไซค์ (motorcycle) ได้แก่ รย. 12 และ 17, รถโดยสาร (bus) คิดจากปริมาณรวมรถโดยสารทั้งหมด และรถบรรทุก (truck) คิดจากปริมาณรวมรถบรรทุกทั้งหมด

Figure 9 Annual Registration of Electric Vehicles in Thailand by Vehicle Type (Data analyzed from the Land Transport Statistics Group, Planning Division, Department of Land Transport), from TESTA Analysis [11].

Based on the registered electric vehicle data in Thailand, it is possible to estimate the volume of battery waste from electric vehicles, which predominantly consists of Nickel-Metal Hydride (Ni-MH) batteries in HEVs and Lithium-Ion batteries in PHEVs and BEVs. The forecasted cumulative battery waste from electric vehicles based on registered electric vehicle data is shown in Figure 10a. It is projected that battery waste will reach 7,000 tons by 2030 and increase to over 30,000 tons by 2031, with over 80% coming from personal electric vehicles. Additionally, when calculating the projected battery waste based on the production and usage plans for electric vehicles in Thailand [12] the estimated battery waste is illustrated in Figure 11b. The forecast indicates that by 2033, the cumulative battery waste will be approximately 200,000 tons. By 2043, the cumulative battery waste is expected to rise to 2,500,000 tons, which represents a substantial amount. Therefore, implementing effective battery management measures to accommodate the rapidly increasing volume of electric vehicle waste is essential for Thailand.



หมายเหตุ: คำนวณจากสมมติฐานการใช้งานและน้ำหนักของแบตเตอรี่ในยานยนต์ไฟฟ้า ดังนี้
1) แบตเตอรี่ที่เสื่อมสภาพถูกใช้งานในยานยนต์ไฟฟ้าเป็นระยะเวลาเฉลี่ย 8 ปี
2) น้ำหนักเฉลี่ยแบตเตอรี่ BEV ในรถยนต์ (car) 280 กิโลกรัม ในมอเตอร์ไซค์ (motorcycle) 30 กิโลกรัม ในรถโดยสาร (Bus) และรถบรรทุก (truck) 1,000 กิโลกรัม
3) น้ำหนักของแบตเตอรี่ HEV และ PHEV คิดเป็น 2% และ 16% ของแบตเตอรี่ BEV ตามลำดับ

Figure 10 Projected Accumulated Battery Waste from Electric Vehicles, estimated from a) Annual Registration of Electric Vehicles in Thailand b) Electric Vehicle Usage Plans in Thailand, from TESTA Analysis [11].

3.2 EV Battery Management Regulations in Thailand

Currently, Thailand does not have specific legislation or regulations solely focused on the management of batteries, including those from electric vehicles. However, as battery waste is classified as hazardous, several related regulations address the management of hazardous substances and environmental protection, including

- **Factory Act B.E. 2535 (1992)**
- **National Environment Quality Promotion and Preservation Act B.E. 2535 (1992)**
- **Hazardous Substances Act B.E. 2535 (1992)**

Additionally, as battery waste is classified as hazardous substance category 9 (miscellaneous dangerous substance), the production, import, export, or possession of such waste requires a license. The relevant regulations include guidelines for registration, storage, transport, and labeling of hazardous substances, as outlined in the pertinent legislation.

- **Transportation** Lithium-ion batteries used in electric vehicles are classified as hazardous material under UN 3481, Category 9. For transportation, operators must obtain permission from the Department of Transport, and drivers must hold a Type 4 driving license issued by the Department of Transport.
- **Management:** Batteries used in electric vehicles, regardless of type, are considered hazardous. Therefore, they must be managed according to hazardous waste management regulations. They must be sent for disposal to licensed collectors and disposal facilities that hold the appropriate hazardous material license (Form 8). Disposal facilities must also be authorized for hazardous waste disposal by the Department of Industrial Works (Factories Type 105 and 106). For battery manufacturing or repackaging, operators must obtain a license for manufacturing, assembling, or modifying electrical equipment not specified in any sequence, including components or equipment of such products (Factory Type 73).
- **Battery Pack Standards:** For electric vehicle battery packs, the cells should be certified to IEC62660, which is the mandatory standard for battery cells used in electric vehicles. Battery packs for small electric vehicles (e.g., electric motorcycles) must meet UN ECE R136 standards, while packs for larger electric vehicles must meet UN ECE R100 standards, as required by the Department of Land Transport for electric vehicle registration in Thailand.

For battery management, the general principle is that it is regulated by the Department of Industrial Works under the Ministry of Industry. The types of factories and business activities related to the management of electric vehicle batteries are summarized in Table 2. From the data on factory types, it can be concluded that if it involves the assembly of new batteries from batteries that are being repurposed, it will be regulated by the requirements for factories listed as No. 73. On the other hand, factories involved in sorting batteries or processing battery materials through recycling processes are primarily regulated by the requirements for factories listed as No. 105 and 106.

Table 2 Details of factory related to EV battery management in Thailand

Factory ID	Detail
73	Factory engaged in the production, assembly, or modification of electrical equipment or appliances not specified in any list, including components or accessories of such products.
105	Factory involved in the sorting or disposal of waste or unused materials with characteristics and properties as specified in Ministerial Regulation No. 2 (B.E. 2535) issued under the Factory Act B.E. 2535.
106	Factory engaged in processing industrial products that are no longer used or waste from factories to produce new raw materials or products through industrial manufacturing processes.

Additionally, Thailand is in the process of the final drafting the "Electric and Electronic Equipment Waste Management Act B.E. ....". The draft aims to make manufacturers of electrical and electronic products responsible for the disposal of waste products or equipment (Extended Producer Responsibility, EPR). Although the act does not yet specify that electric vehicle batteries will be included, there has been a discussion that batteries from electric vehicles or even electric vehicles themselves could be categorized as part of the electrical and electronic equipment waste under this act. Those involved in the production and disposal of electric vehicle batteries should thus closely monitor the progress of this legislation.

Currently, Thailand lacks specific systems and laws for managing electric vehicles, so the management of end-of-life electric vehicle batteries largely depends on the actions of manufacturers and disposal companies. For instance, if an electric vehicle battery is still under warranty, users typically return the vehicle and battery to the manufacturer for a replacement. The manufacturer then handles the disposal of the old battery. However, if the battery is out of warranty, users are responsible for its disposal, which might involve disposal fees or improper disposal practices. Additionally, batteries involved in accidents have disposal pathways that depend on insurance companies, which may lead to improper disposal as well.

3.3 End of Life EV Battery Management Pathway in Thailand

Due to the absence of specific regulations on battery management in Thailand, the management of batteries is largely carried out by the stakeholders themselves. Additionally, Thailand currently lacks dedicated lithium-ion battery recycling facilities, resulting in batteries being exported for disposal abroad. From a study of data from stakeholders in the battery value chain, the management paths for end-of-life batteries can be summarized and categorized based on their usage and case.

3.3.1 Pathway 1: EV batteries under warranty

Pathway of batteries in electric vehicles under warranty is shown in Figure 11, batteries are produced and used in electric vehicles. Waste from the battery production process is directly sent to battery recycling companies for disposal. For batteries that are already in use, they are assembled into electric vehicles or energy storage systems and sold to users. After usage, if the battery is still under warranty, users generally notify the manufacturer or distributor to replace the battery. The manufacturer or distributor then manages the disposal of the battery, which may include repair, remanufacturing, or repurposing. After the repair or refurbishment, the battery may be reused in its original application or for new purposes, such as being sold to manufacturers or distributors of energy storage systems. If the battery cannot be repaired or refurbished, it will then be sent for disposal, possibly to battery recycling companies, where the battery or its materials will be recycled abroad.

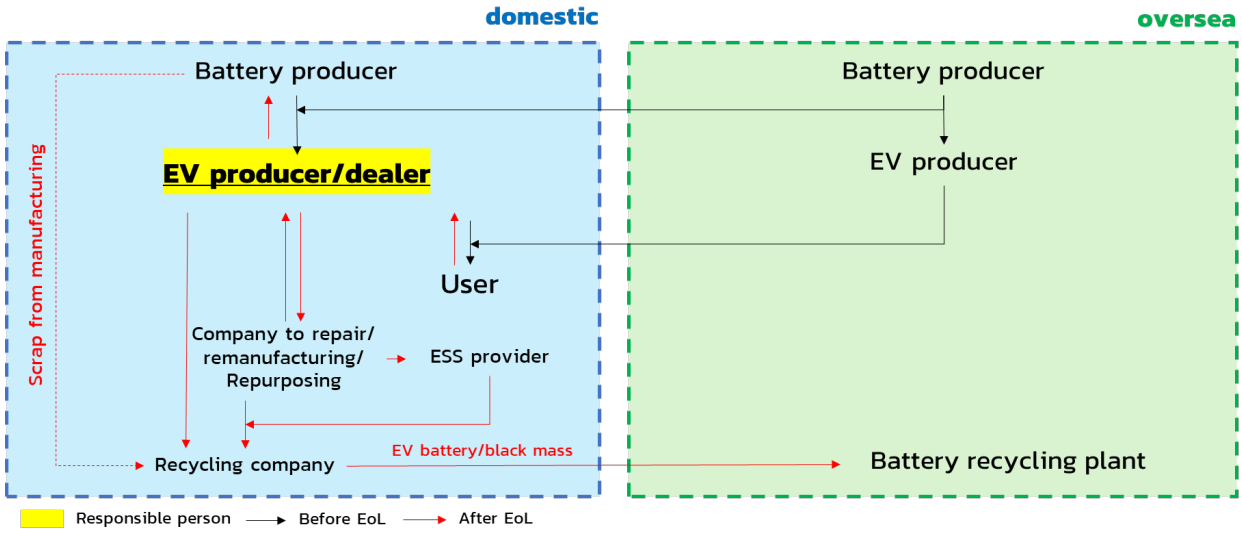


Figure 11 Pathway of EV batteries under warranty

3.3.2 Pathway 2: EV batteries without warranty

Pathway of batteries in electric vehicles or energy storage systems (when the product warranty is expired or not applicable) is illustrated in Figure 12. Batteries are produced and used in electric vehicles. Waste from the battery production process is directly sent to a battery recycling company for disposal. The produced batteries are integrated into electric vehicles or energy storage systems and sold to users. After use, if the warranty period has expired, the user becomes the primary party responsible for managing the battery. The user may either replace the old battery with a new one through the manufacturer or supplier of the electric vehicle or energy storage system, or manage the disposal themselves. This can involve sending the deteriorated battery for repair, remanufacturing, or repurposing. After repair or refurbishment, the battery might be used for its original purpose or for new applications, such as being sold to manufacturers or distributors of energy storage systems. If the battery cannot be repaired or refurbished, it will be sent for disposal, potentially to a battery recycling company, where the battery or its materials will be recycled abroad. Due to the costs associated with replacing a battery after the warranty period or self-disposal, users might opt to manage the battery themselves, potentially outside the regulated system. This could involve disposing of the battery with regular waste, illegal dumping, or selling it to second-hand battery buyers domestically or internationally. Such practices pose environmental risks or hazards to communities, indicating a risk of improper management.

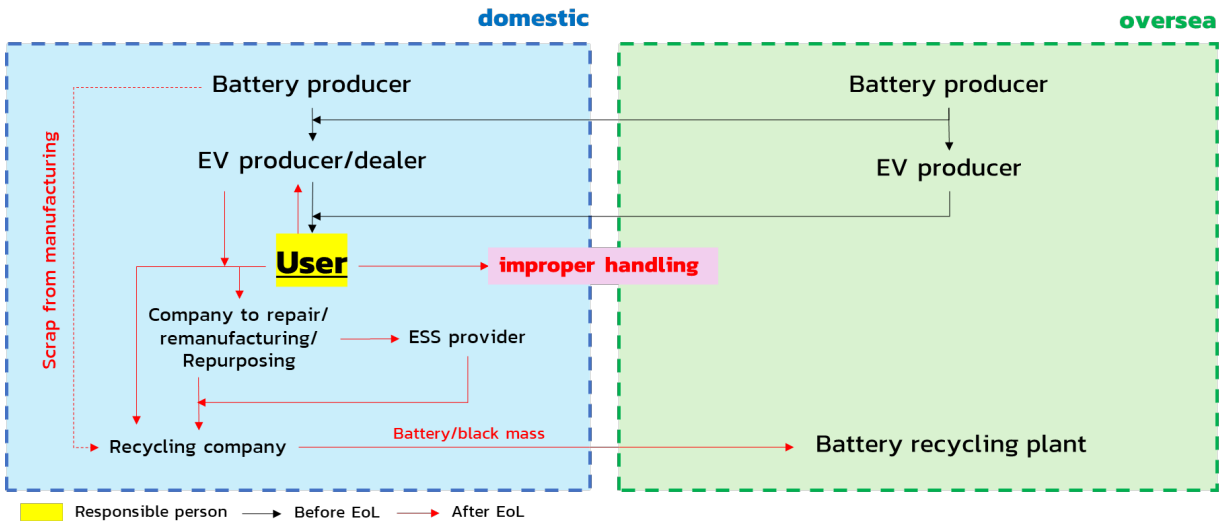


Figure 12 Pathway of EV batteries without warranty

3.3.3 Pathway 3: Swappable or rental EV batteries

The pathway for the production and management of batteries in swappable or rental is shown in Figure 13. Batteries are produced and used in electric vehicles with battery swapping systems. Waste from the battery production process is directly sent to battery recycling companies. For batteries that have been produced, they are sold to manufacturers/suppliers of battery-swapping electric vehicles and used by consumers. Since the battery-swapping service operates on a rental basis, the battery owner is the manufacturer/supplier of the battery-swapping system, which is the primary party responsible for managing the battery when it reaches the end of its life. The management process includes repair, remanufacturing, or repurposing. After repair or refurbishment, the battery may be reused in the same application or for new applications, such as resale to energy storage system manufacturers or distributors. If the battery cannot be repaired or refurbished, it will be disposed of, possibly by sending it to a battery recycling company, where the battery or its materials will be recycled oversea.

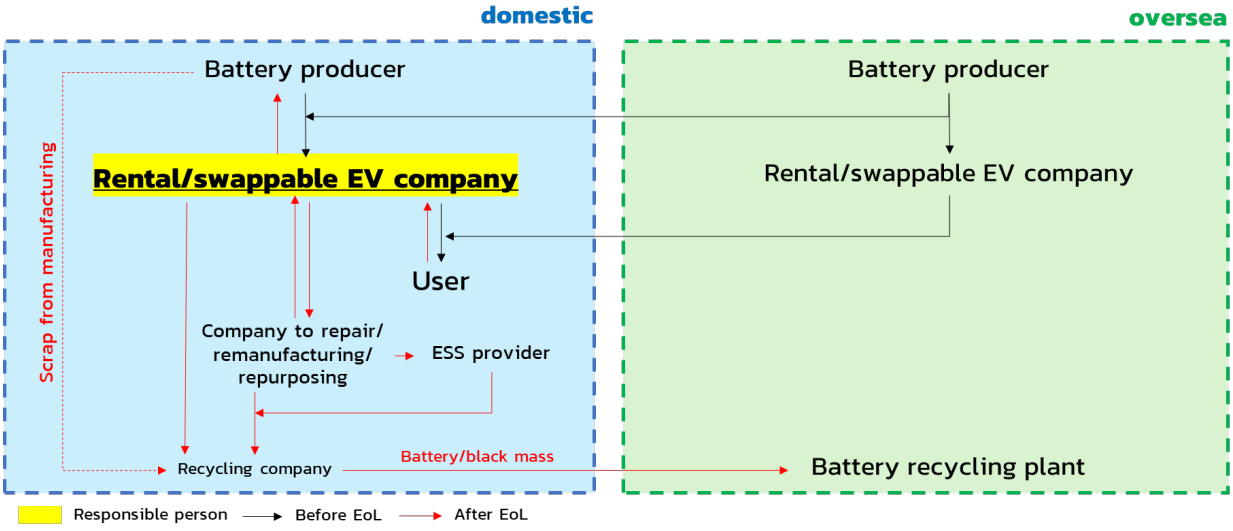


Figure 13 Pathway of swappable or rental EV batteries

3.3.4 Pathway 4: Post-accident EV batteries under insurance coverage

Pathway of batteries damaged from accidents where insurance coverage is provided, in Figure 14. Batteries will be produced and used in electric vehicles. Waste from the battery production process is sent directly to a battery recycling company for disposal. Batteries that have already been produced are assembled into electric vehicles or energy storage systems and sold to end users. In the event that a battery is damaged from an accident, the insurance company is primarily responsible for its disposal. If the battery is still in good condition and can potentially be reused, it may be subject to repair, remanufacturing, or repurposing. After repair or refurbishment, it may be used for the original purpose or a new application, such as being sold to manufacturers or energy storage system providers. However, if the battery cannot be repaired or refurbished, it will be sent for disposal, potentially to a hazardous waste management company or a battery recycling company that handles accident-damaged batteries. The battery or its components will then be recycled abroad. Batteries from accident-damaged electric vehicles pose significant hazards in handling, requiring careful attention to transportation, storage, and management to ensure safety. Additionally, there may be instances where operators improperly dispose of batteries outside the formal system, such as mixing them with general waste, illegal dumping, or sending them to second-hand battery buyers both domestically and internationally. Improper storage can also lead to safety hazards. Therefore, there is a high risk associated with the management of these batteries, although insurance companies, as legal entities, are subject to hazardous waste disposal regulations.

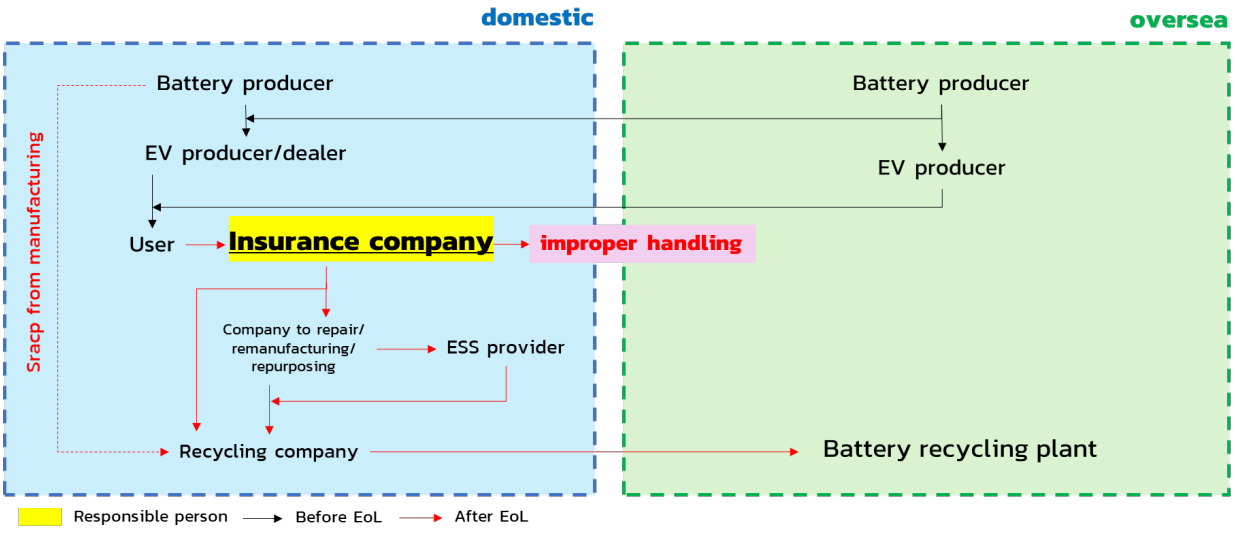


Figure 14 Pathway of post-accident EV batteries under insurance

3.3.5 Pathway 5: Post-accident EV batteries without insurance coverage

Pathway of accident-damaged batteries without insurance coverage is illustrated in Figure 14, batteries will be produced and used in electric vehicles. Waste from the battery production process is sent directly to a battery recycling company for disposal. Batteries that have been produced are assembled into electric vehicles or energy storage systems and sold to end users. However, if a battery is damaged from an accident but does not have insurance coverage, the user is primarily responsible for its disposal. The user may either replace the damaged battery with a new one through the manufacturer or seller of the electric vehicle or energy storage system, or handle the disposal independently. The disposal process may involve sending the degraded battery for repair, remanufacturing, or repurposing. After repair or refurbishment, the battery may be reused for its original purpose or for a new application, such as being sold to manufacturers or energy storage system providers. If the battery cannot be repaired or refurbished, it will be sent for disposal, potentially to a hazardous waste management company or a battery recycling company that handles accident-damaged batteries. The battery or its components will then be recycled abroad. Batteries from accident-damaged electric vehicles present significant hazards in handling, requiring careful attention to transportation, storage, and management to ensure safety. Additionally, since the user is responsible for disposal, there is a risk of improper disposal, such as mixing with general waste, illegal dumping, sending to second-hand battery buyers both domestically and internationally, or improper storage leading to safety hazards. There is a high risk associated with managing these batteries if users are not informed about proper disposal methods for accident-damaged batteries.

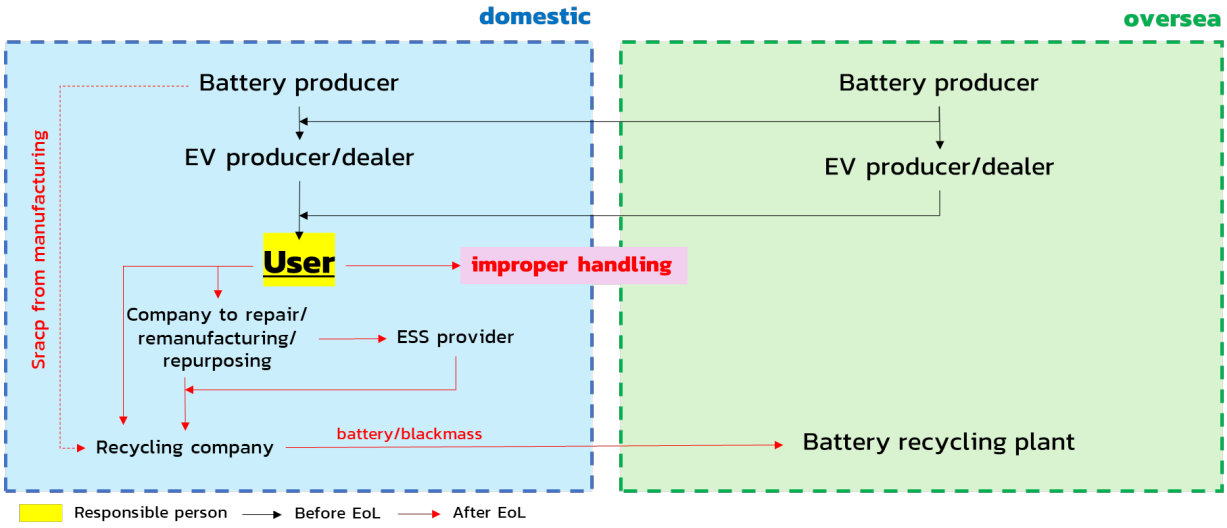


Figure 15 Pathway of post-accident EV batteries without insurance coverage

From the battery management pathways for different use cases, it is evident that various approaches are employed due to the lack of specific and mandatory disposal regulations in Thailand. Consequently, the risk in battery management primarily rests with the responsible parties. If the primary responsible party is the end user and the disposal is handled by individuals, there is a high risk that the battery waste may be managed improperly. This is particularly true in cases involving batteries in electronic devices, batteries in electric vehicles or energy storage systems that are out of warranty, or accident-damaged batteries without insurance. On the other hand, if the responsible party is the operator or battery manufacturer, the risk of improper management is lower to moderate, as disposal operations are regulated by laws concerning industrial facilities. This includes cases such as waste batteries from production processes, batteries in electric vehicles or energy storage systems still under warranty, swappable electric vehicle batteries, and accident-damaged batteries with insurance, managed by operators or legal entities. The risks in management can be summarized as shown in Table 3. The government may consider enacting laws, regulations, or support measures to address the high-risk scenarios of improper battery disposal.

Table 3 Summary of responsibilities and risks in battery management for Each pathway

Pathway of EV batteries	Responsible person	Risk on improper handling
1. EV batteries under warranty	EV producer/dealer	LOW
2. EV batteries without warranty	User	HIGHT
3. swappable or rental EV batteries	Swappable/rental EV company	LOW
4. Post-accident EV batteries under insurance coverage	Insurance company	MEDIUM
5. Post-accident EV batteries without insurance coverage	User	HIGHT

Future Outlook and Recommendations for End-of-Life Battery Management in Thailand

4

Battery usage in Thailand aligns closely with global trends, particularly in the growing adoption of electric vehicles (EVs). This chapter provides a comprehensive review of the trends in EV adoption within Thailand, along with projections for future EV battery waste. It also examines the regulatory framework governing EV battery management in the country. The current lifecycle of EV batteries, from production to end-of-life, is discussed in detail, highlighting the processes and challenges involved. Based on these insights, recommendations for enhancing EV battery recycling policies in Thailand are proposed, aiming to address the anticipated increase in battery waste and improve sustainability in the EV sector.

4.1 Issues on EV Battery Management in Thailand

Based on data obtained via interviews with stakeholders namely:

1. **Battery Manufacturers: Including both cell manufacturers and battery pack assemblers.**
2. **Electric Vehicle Manufacturers or Sellers.**
3. **Energy Storage System Designers or Installers.**
4. **Battery Disposal Operators.**

Information obtained from over stakeholders in each segment of the battery value chain regarding battery management in the country is summarized in Table 4. For battery manufacturers, issues include the customs tariff classification of battery waste from battery production facilities. Currently, this is often calculated using the same cost basis as new battery cells, resulting in battery manufacturers incurring waste disposal taxes based on the cost of new cells. Additionally, since Thailand does not yet have specific regulations for end-of-life battery management, battery manufacturers must manage battery waste using their own methods. The import of battery waste into the country is currently not premitted, which prevents the importation of battery waste or components for new cell production or repurposing. If feasible, import duties on batteries or battery parts should be waived to support recycling or repurposing of batteries in Thailand.

Regarding storage and transportation, current regulations are aligned with those for other hazardous materials. Given the risks associated with transporting and storing battery waste, specific regulations for battery waste storage and transportation should be established. Furthermore, Thailand should implement and enforce a national traceability system for batteries, which could be integrated with international systems. For future battery cell production, Thailand could promote the use of recycled materials in battery cell manufacturing by specifying minimum amounts of recycled materials in battery cell components.

For electric vehicle manufacturers/sellers, there are comments regarding battery management approaches. Currently, the management of used batteries is largely based on the practices of their parent companies abroad, which are often tied to the regulations of those countries. Since Thailand does not yet have specific battery management guidelines, some stakeholders believe that a fund-based system, which could follow Extended Producer Responsibility (EPR) principles, may not be necessary if Thailand establishes clear regulations specifying primary responsibility for battery management. This is because a fund-based system might encounter issues in its management. Battery management issues are anticipated primarily with batteries that are out of warranty from electric vehicles, as the responsibility for their management falls to the users. This can lead to improper and potentially hazardous handling of batteries. Therefore, Thailand should implement measures for tracking batteries to facilitate the retrieval of out-of-warranty batteries, including systematic measures and pathways for managing out-of-warranty batteries. Additionally, it is suggested that battery management should not be treated the same as electronic waste management due to differing management requirements. For repurposing or recycling batteries, it is recommended that battery manufacturers determine which batteries can be reused or what methods should be used to ensure safety in their repurposing.

For energy storage system designers/installers, there are comments that the government should establish clear regulations or measures for battery management. Testing batteries for reuse or repurposing involves high costs, which may make it economically unfeasible. Therefore, it is suggested that the government should support the costs of testing these batteries. Additionally, it is noted that handling entire battery packs without sorting them into modules or packs is considered the most cost-effective approach.

For battery disposal agencies, there are comments that the current volume of battery waste is still low, which makes domestic recycling unprofitable. Since Thailand does not yet have recycling facilities, batteries must be exported for disposal, incurring high transportation costs, with roughly half of these costs being shipping expenses. Therefore, Thailand should consider policies to import used batteries or their components to increase the volume of battery waste available for domestic recycling. Regarding storage and transportation, existing regulations are applied to hazardous materials in general. Given the risks associated with transporting and storing battery waste, specific regulations for these processes should be established. Additionally, Thailand should support policies that include subsidies, tax reductions, or exemptions for businesses involved in battery management to promote increased domestic handling of batteries.

Table 4 Comments from stakeholders in each segment of the battery value chain regarding battery management in Thailand

Value Chain	Feedback
Battery Manufacturing	• The issue of customs classification for battery waste from battery manufacturing plants, where the cost is the same as that for new battery cells. • There should be regulations specifically for managing batteries after their end-of-life. • Promote and support/allow the import/export of battery waste, including scrap from the production process or black mass (potentially allowing only in designated areas). • Exempt import taxes on used batteries or battery parts intended for recycling or reuse in the country. • There should be clear legal provisions or guidelines for the storage and transportation of used batteries, specifically to ensure safety standards. • There should be a national traceability system for batteries that can be integrated with international systems. • Support the use of recycled materials in domestic battery cell production (e.g., by providing partial subsidies or setting minimum recycled material ratios to promote material circulation within the country)

Value Chain	Feedback
Electric Vehicle Production	• Since Thailand lacks battery management legislation, most operations are based on the management guidelines of the parent companies abroad, which are often tied to the regulations of those countries. • A fund system for battery management may not be necessary if Thailand has clear legislation on battery management specifying the primary responsible parties, as fund systems may encounter management issues. • There should be development of a battery tracking system, especially for out-of-warranty batteries, to ensure proper management and return of those batteries. • Relevant agencies should implement measures for managing out-of-warranty batteries to ensure they are properly handled. • Battery management measures should not be treated the same as electronic waste management due to differing management practices. • The responsibility to determine whether batteries can be reused or what management method should be used should be assigned to the manufacturers.
ESS Installation	• The government should issue clear regulations or measures for battery management. • The cost of testing batteries after repurposing is high, which may render it economically unviable. The government should have measures to support the testing of repurposed batteries. • Repurposing batteries as a complete pack, without separating them into modules or cells, is the most cost-effective approach.
Battery management	• The current volume of battery waste is still low, making domestic recycling not yet cost-effective. • Exporting batteries for disposal abroad incurs high shipping costs, with nearly 50% of the disposal costs attributed to shipping. • There should be a policy to allow the import of used batteries or components from used batteries to increase the volume of battery waste available for domestic recycling. • Safety standards for transporting battery waste domestically are crucial. There should be specific measures for transporting used battery waste. • There should be policies to support financial subsidies, tax reductions, or exemptions for businesses involved in battery management to promote domestic battery management.

4.2 Summary of Recommendations for Battery Management in Thailand

Based on the collected feedback from stakeholders involved in battery management in Thailand, the Thai Energy Storage Technology Association has summarized recommendations for battery management in Thailand to aid in the development and promotion of policies supporting battery management in the country, as outlined in Table 5. These recommendations are categorized into four areas:

4.2.1 Policy and data requirements

In the area of policy and data requirements, since Thailand currently lacks specific measures and guidelines for battery management, it is essential for the country to establish laws, regulations, or measures specifically for managing used batteries. This should include clearly identifying the main responsible parties to create a consistent standard for battery management within the country. There should be clear identification of battery return recipients and transparency in battery information to aid in designing the disposal process by waste managers. This could involve a product labeling system that allows information to be retrieved from the labels. There should be a push to develop a battery tracking system to monitor the process through which batteries are handled and ensure that batteries can be accurately and systematically tracked for retrieval and disposal.

4.2.2 Transportation and storage

In the area of transportation and storage, efforts should be made to promote efficient management of batteries after their end-of-life, including support for handling batteries from electric vehicles that are out of warranty, small batteries from electric motorcycles, and other electronic devices for which users are responsible for disposal. This is to reduce improper and hazardous management and minimize environmental impact. Additionally, Thailand should establish standards or regulations for the storage and transportation of used batteries, including licensing for transportation and storage. Proper management of battery sorting based on their condition after end-of-life should be promoted, with storage and transportation categorized according to the battery's condition to enhance safety for those involved in handling and transporting used batteries.

4.2.3 Promoting the enhancement of value for optimal use

In the area of promoting the enhancement of value for optimal use, there should be clear standards or regulations regarding the repurposing of batteries from electric vehicles. This includes clearly defining the customs classification for repurposed batteries. If the import of used battery cells is permitted, there should be specific tax classifications for these used batteries, potentially with labels indicating that they are repurposed batteries. This will encourage the extension of the lifespan of electric vehicle batteries, ensuring they have continued value and meet safety standards. Support should be provided to capable operators to develop the battery repurposing or recycling industry through various forms of support, such as BOI (Board of Investment) packages, subsidies, or low-interest loans, to increase recycling and material circulation within the country.

4.2.4 Promoting the recycling industry

In the area of promoting the recycling industry, support should be provided for the import of battery waste or components of battery waste to achieve economies of scale. This could include allowing or reducing import taxes on used batteries or their components to increase the volume of used batteries available for cost-effective recycling. This would reduce the costs associated with proper disposal for the automotive industry, alleviate the burden and risk of transporting waste abroad, and decrease unsafe dumping caused by high expenses. Supporting proper management of used batteries would also help build an industry within the value chain following the electric vehicle battery industry, reduce domestic waste management needs, and enhance the value within the battery value chain. For future support of Thailand's battery recycling industry, there could be support for related industries within the value chain post-recycling, such as the chemical industry and other by-products from batteries, to reuse recycled materials. This would enhance the capacity for storage, promote new industries for recycling waste products into raw materials, and support high-value related industries. Additionally, promoting the use of recycled materials in domestic battery cell production could involve subsidies for recycled material use and setting minimum ratios for recycled materials in battery cell production to increase the use of recycled materials in domestic battery manufacturing.

Table 5 Summarizes recommendations for battery management in Thailand and the expected outcomes.

	Recommendation	Expected Outcomes
Policy and Data Requirements	Establish laws, regulations, or measures for battery management, clearly defining the main responsible parties.	Establish a clear and consistent standard for battery management within the country.
	Implement regulations/standards for mandatory disclosure of minimum battery information, such as battery type, components, manufacturer, and post-end-of-life responsibility.	Create a standard for battery information, including details about the responsible parties and necessary data for effective end-of-life battery management.
	Develop a tracking and reporting system for batteries throughout the value chain, designate responsible parties for tracking, and set storage goals.	Enable tracking of batteries from production and use through to management, allowing battery managers to handle them properly and measure the efficiency of storage.
Transportation and Storage	Support the establishment of systematic and standardized regulations for the storage and transportation of used batteries, including licensing for transportation and storage. This should also include managing the sorting of batteries based on their condition post-end-of-life, such as degraded but not physically damaged, degraded with minor physical damage, and fully damaged (e.g., fire).	Enhance the safety of those involved in the storage and transportation of used batteries, which may pose risks during handling.
	Support and promote systems for the efficient handover, transfer, and management of end-of-life batteries. This should not be limited to large electric vehicles but also include batteries from out-of-warranty electric vehicles, small batteries from electric motorcycles, and other electronic devices. Additionally, provide guidelines for proper management and public awareness.	Reduce illegal and unsafe dumping, enhance safety, decrease environmental impact, and increase storage capacity while promoting new industries focused on utilizing waste materials as resources.
Promoting the enhancement of value	Establish clear standards or regulations for the safe repurposing of batteries from electric vehicles, including specifying the tax code for repurposed batteries.	Promote extending the lifespan of batteries from electric vehicles to ensure their continued value and adherence to safety standards.
	Support potential operators in developing industries for battery recycling or repurposing through various forms of support, such as BOI packages, subsidies, or low-interest loan programs.	Increase domestic recycling and material circulation of batteries, reduce national waste, and enhance the value of electric vehicle batteries in developing a green industry.

Table 5 Summarizes recommendations for battery management in Thailand and the expected outcomes.

	Recommendation	Expected Outcomes
Promoting recycling industry	Promote measures to ensure a sufficient volume of batteries for achieving economy of scale, such as permitting or reducing import taxes on used batteries or their components.	Increase the volume of used batteries to ensure sufficient quantities for cost-effective recycling, reduce disposal costs for the automotive industry, decrease the burden and risks associated with exporting for disposal, and minimize unsafe disposal practices due to high costs. Support the proper management of used batteries, create industries in the value chain following the electric vehicle battery industry, reduce domestic waste that needs to be managed, and enhance the potential and value in the battery value chain.
	Support downstream industries in the value chain after recycling, such as chemical industries and other sectors that benefit from recycled battery materials, and invest in the development of related technologies.	Enhance storage capabilities, promote new industries related to converting waste into resources, and encourage high-value related industries.
	Encourage the use of recycled materials in domestic battery cell production by providing subsidies for using recycled materials and setting minimum recycling content requirements for battery cells.	Increase the use of recycled materials in domestic battery production and promote high-value related industries.

Definition: For the purpose of this document, “battery” refers to rechargeable batteries, excluding lead-acid batteries.

Refference

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McKinsey & Company, Global Battery Alliance, Battery 2030: Resilient, sustainable, and circular, 2022. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular (accessed August 30, 2024).

McKinsey & Company, Battery recycling takes the driver's seat, 2023. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-recycling-takes-the-drivers-seat (accessed August 30, 2024).

A Vision for a Sustainable Battery Value Chain in 2030 Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation including photocopying and recording, or by any in formation storage and retrieval system. 3 A Vision for a Sustainable Battery Value Chain in 2030: Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation, 2019. www.weforum.org.

C. Tsinghua UniversityUnited Nations Environment ProgrammeBasel Convention Regional Centre for Asia and the Pacific, Guidance Manual on Used and Waste EV Batteries-Case Studies in China, 2021.

R. Sommerville, J. Shaw-Stewart, V. Goodship, N. Rowson, E. Kendrick, A review of physical processes used in the safe recycling of lithium ion batteries, Sustainable Materials and Technologies 25 (2020). https://doi.org/10.1016/j.susmat.2020.e00197.

M. Chen, X. Ma, B. Chen, R. Arsenault, P. Karlson, N. Simon, Y. Wang, Recycling End-of-Life Electric Vehicle Lithium-Ion Batteries, Joule 3 (2019) 2622–2646. https://doi.org/10.1016/j.joule.2019.09.014.

D.L. Thompson, J.M. Hartley, S.M. Lambert, M. Shiref, G.D.J. Harper, E. Kendrick, P. Anderson, K.S. Ryder, L. Gaines, A.P. Abbott, The importance of design in lithium ion battery recycling-a critical review, Green Chemistry 22 (2020) 7585–7603. https://doi.org/10.1039/d0gc02745f.

Z.J. Baum, R.E. Bird, X. Yu, J. Ma, Lithium-Ion Battery RecyclingOverview of Techniques and Trends, ACS Energy Lett 7 (2022) 712–719. https://doi.org/10.1021/acsenergylett.1c02602.

European Union, Regulation (EU) 2023/1542 on batteries and waste batteries, 2024. https://eur-lex.europa.eu/eli/reg/2023/1542/oj (accessed August 30, 2024).

Z. Kang, Z. Huang, Q. Peng, Z. Shi, H. Xiao, R. Yin, G. Fu, J. Zhao, Recycling technologies, policies, prospects, and challenges for spent batteries, IScience 26 (2023). https://doi.org/10.1016/j.isci.2023.108072.

Thailand Energy Storage Technology Association (TESTA), Overview of the Situation, Issues, and Recommendations for End-of-Life Battery Management (in Thai), 2024. https://www.testa.or.th/knowledge/ (accessed August 29, 2024).

Thailand Automotive Institute (TAI), Thailand's EV Production and Use Targets, (2021). https://www.thaiauto.or.th/2020/news/?news_id=4981 (accessed August 30, 2024).