Analysis of the Current Situation of New Energy Vehicle Battery Recycling Technologies

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Abstract: This paper focuses on the current situation of new energy vehicle battery recycling technologies. With the rapid development of the new energy vehicle industry, the problem of battery recycling has become prominent. It is of great significance for resource utilization, environmental protection, and the sustainable development of the industry. The paper deeply analyzes three main recycling technologies: physical method, chemical method, and biological method. The physical method is simple to operate, environmentally friendly, and has a wide range of applications, but it has problems such as low efficiency, deterioration of material performance, and inability to process lithium - iron phosphate batteries. The chemical method has advantages such as high recovery rate, strong flexibility, and environmental friendliness, but it has high costs, high energy consumption, and complex waste management. The biological method has high environmental friendliness, low cost, and strong sustainability, but it has low efficiency, great technical challenges, and a limited application range. By comprehensively comparing the advantages and disadvantages of these three technologies, this paper provides a theoretical basis for further optimizing battery recycling technologies and promoting the sustainable development of the new energy vehicle industry.

1. Introduction

With the increasing global emphasis on environmental protection and sustainable development, new energy vehicles, as an important alternative to traditional fuel vehicles, have witnessed rapid development in recent years. According to data from the China Association of Automobile Manufacturers, in 2023, the production of new energy vehicles in China reached 9.587 million units, and the sales volume reached 9.495 million units, with year - on - year growth of 35.8% and 37.9% respectively, and the market share reached 31.6%. The rapid growth of new energy vehicles not only helps to reduce carbon emissions and dependence on traditional fossil energy but also promotes the transformation and upgrading of the automotive industry.

However, the large - scale popularization of new energy vehicles has also brought new challenges, among which the battery recycling problem is particularly prominent. The power batteries used in new energy vehicles contain various valuable metals such as lithium, cobalt, and nickel. These metal resources are limited and have high mining costs. If waste batteries are not properly recycled and processed, it will not only cause a great waste of resources but also pose a serious threat to the environment and human health.

The development of battery recycling technology is of great significance for the sustainable development of the new energy vehicle industry. From the perspective of resources, recycling valuable metals from waste batteries can effectively reduce dependence on natural resources and lower raw material costs. For example, lithium is a key raw material for power batteries. Since global lithium resources are unevenly distributed, recycling lithium can alleviate the resource shortage. From an environmental perspective, properly handling waste batteries can prevent the leakage of heavy metals and chemical substances from polluting soil, water sources, and air, reducing environmental risks. A sound battery recycling system can also enhance the overall image of the new energy vehicle industry, boost consumers' confidence in new energy vehicles, and

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promote the healthy and sustainable development of the industry.

2. Analysis of Physical Recycling Methods

2.1 Recycling Principle

The physical recycling method mainly uses means such as mechanical crushing, sorting, and separation to physically separate the materials in waste batteries, thereby extracting valuable metals and materials. For example, metals such as iron, aluminum, and copper can be separated through crushing and magnetic separation, and elements such as lithium and cobalt can be further separated through flotation technology [1].(Figure 1&2)

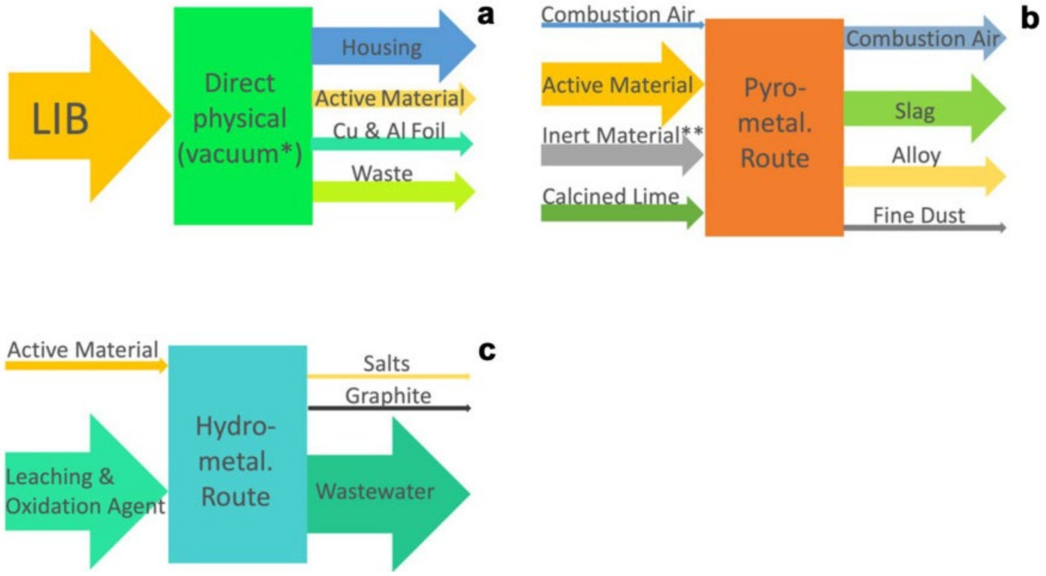

Figure 1 Physical Recycling Process

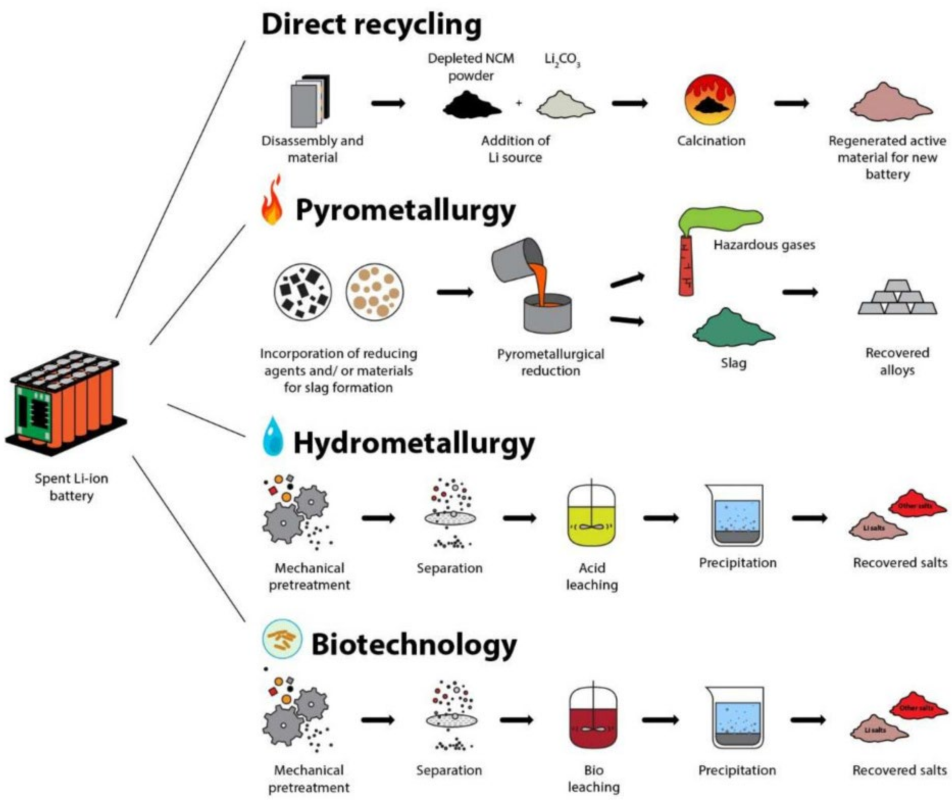

Figure 2 Overview of Various Recycling Method Processes

2.2 Advantages of Physical Recycling Method

Simple and Feasible: The physical method does not require complex chemical treatment processes. It is relatively easy to operate and has a low cost [2].(Figure 3&4)

Technology	Advantage	Disadvantage
Mechanical physics method	➢ Low operational cost ➢ Absence of chemical usage ➢ No solvent contamination ➢ Minimal cost for consumables	➢ Time consuming ➢ Labor intensive process ➢ Low efficiency ➢ Incomplete metal recovery
Pyrometallurgy	➢ Applicability to any type of electronic waste ➢ No need for pretreatment ➢ Less process steps	➢ Plastic cannot be recycled ➢ High costs and energy consumption ➢ Low product purity
Hydrometallurgy	➢ High recovery ➢ No gaseous pollutants emission ➢ Less sensitivity to base metals ➢ Recyclable	➢ High cost of reagents ➢ Limited availability ➢ High toxicity ➢ Need for mechanical pretreatment of the scrap
Biological treatment	➢ Economic and simple ➢ Ecofriendly process ➢ Less energy requirement	➢ Relatively slow process ➢ Dependent on operational conditions ➢ Unstable processing effect

Figure 3 Comparison of Advantages and Disadvantages of Various Recycling Methods1

Method	Advantages	Disadvantages
Direct recycling	Environmentally friendly; High specificity; Non-destructive method.	Non-specific; Not possible processing of different cathode materials.
Pyrometallurgical method	High recycling rates; Solvent free.	High-temperature process; Other processes for the effective recovery of materials are necessary.
Hydrometallurgical method	High recycling rates; Large variety in the recovery of metals.	Complexity of the process; Application of toxic reagents; High in costs.

Figure 4 Comparison of Advantages and Disadvantages of Various Recycling Methods2

Recycling Method	Advantages	Disadvantages
Pyrometallurgy	• Flexible; applicable to any battery chemistry and configuration • No sorting or other mechanical pre-treatment necessary • High recovery of metals (e.g., Co, Ni, and Cu) • Proven technology; can be implemented using existing pyrometallurgical facilities	• Cannot recycle Li, Al, or organics • Cannot treat LFP batteries • Expensive gas clean-up is required to avoid toxic air emissions • Energy intensive • Capital intensive • Further refinement is necessary to produce elemental metals from metal alloys produced in smelting process
Hydrometallurgy	• Applicable to any battery chemistry and configuration • Flexible in separation and recovery processes to target specific metals • High recovery rates (e.g., for lithium) • High purity of products (suitable for cathode precursors, etc.) • Energy efficient • No air emissions	• Battery cells must be crushed (causing safety concerns) • Acid breaks down cathode structure • High volume of process effluents to be treated and recycled or disposed • Not economical for lithium iron phosphate (LFP) batteries • Anode materials (e.g., graphite and conductive additives) are not recovered • High operating cost
Direct recycling	• Retains valuable cathode structure • Practically all battery materials can be recovered, including anode, electrolyte, and foils • Suitable for LFP batteries • Energy efficient • Convenient for recycling manufacturing scraps	• Complex mechanical pre-treatment and separations are required • Recovered material may not perform as well as virgin material or becomes obsolete by the time it is introduced to market • Mixing cathode materials could reduce the value of recycled product • Regeneration processes yet to be developed • Not scaled up to industrial level

Figure 5 Comparison of Advantages and Disadvantages of Various Recycling Methods3

High Environmental Friendliness: It does not involve the use of harmful chemical reagents, reducing environmental pollution [3].

Wide Applicability: It is suitable for battery materials with complex structures or diverse components [4].(Figure 5)

2.3 Recycling Limitations

Low Efficiency: Due to its inability to effectively separate light metals such as lithium and aluminum, the recovery rate is low [5].(Figure 6)

	Dry method	Wet method	Direct Recycling
Strength	- Free to mix the ingredients - sorting is unnecessary - commercially proven process	- Low-capacity facilities - Low temperature/low energy process - High purity - Lithium and manganese can be recovered	- No changes in the anode material chemical structure - Low temperature/low energy process
Weakness	- The problem of recovering lithium, aluminum, and manganese - High temperature process - Need to get rid of exhaust gas - High investment costs - Glass for high-capacity treatment	- Need to preprocess (raw material powder) - Wastewater treatment	- Only use a single model

Figure 6 Comparison of Advantages and Disadvantages of Various Recycling Methods4

Deterioration of Material Performance: Physical treatment may lead to a decline in material performance. For example, the capacity and lifespan of batteries will be affected [6].

Inability to Process Lithium - Iron Phosphate Batteries (LFP): The physical method cannot effectively recycle lithium in LFP batteries .

3. Analysis of Chemical Recycling Method

3.1 Recycling Principle

The chemical recycling method uses chemical solvents or acidic solutions to dissolve the active substances in waste batteries, thereby extracting metals such as lithium, cobalt, and nickel. For example, hydrometallurgy dissolves the positive electrode material by using sulfuric acid or other solvents, and then separates the required metals through precipitation or electrolysis [7].

3.2 Advantages of Chemical Recycling Method

High Recovery Rate: It can efficiently extract various valuable metals, such as lithium, cobalt, and nickel [8].

Strong Flexibility: It is applicable to batteries with different chemical compositions and structures and can flexibly adjust the process to meet specific requirements .

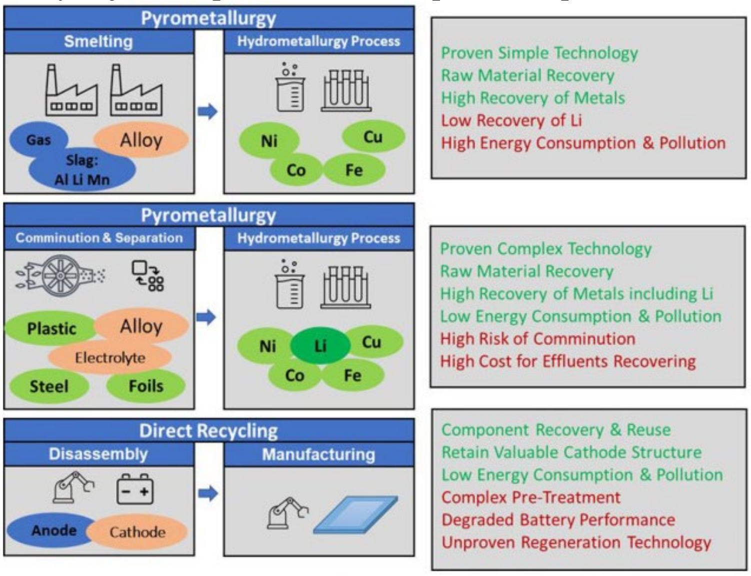

Figure 7 Chemical Recycling Process

Environmentally Friendly: Compared with pyrometallurgy, the chemical method produces fewer harmful gases and has a smaller impact on the environment [9].(Figure 7)

3.3 Recycling Limitations

High Cost: It requires the use of expensive chemical reagents, and a large amount of waste liquid and by - products are generated during the treatment process, resulting in high treatment costs [10].

High Energy Consumption: Some chemical treatment processes require high - temperature or high - pressure conditions, consuming a large amount of energy .

Complex Waste Management: The generated waste liquid and by - products need to be properly disposed of; otherwise, secondary pollution may occur .

4. Analysis of Biological Recycling Method

4.1 Recycling Principle

The biological recycling method uses the catalytic action of microorganisms or enzymes to decompose the active substances in waste batteries, thereby extracting metals such as lithium and cobalt. For example, the bacterium Thiobacillus ferrooxidans is used to decompose nickel in nickel - cadmium batteries [11].

4.2 Advantages of Biological Recycling Method

High Environmental Friendliness: The biological method does not use chemical reagents, avoiding the emission of harmful substances, and is a green recycling method .

Low Cost: The energy consumption of the microbial metabolism process is low, and expensive chemical reagents are not required .

Strong Sustainability: Microbial technology has high renewability and sustainability .

4.3 Recycling Limitations

Low Efficiency: The biological recycling process is slow, with a low reaction rate, making it difficult to meet large - scale industrial demands .

Great Technical Challenges: The controlled conditions are harsh. For example, the temperature, pH value, etc. need to be strictly controlled, and the microbial activity is easily affected by the external environment .

Limited Application Scope: Currently, the biological method is mainly in the laboratory research stage and has not been widely applied in industrial production .

5. Summary

The new energy vehicle industry is booming. In 2023, the production and sales of new energy vehicles in China increased significantly, and the market share rose remarkably. However, the recycling of waste batteries is a serious problem. If not properly handled, it will cause resource waste and environmental pollution. Currently, the main battery recycling technologies include physical, chemical, and biological methods.

Physical Method: It recycles materials through mechanical crushing, sorting, and separation. It is simple to operate, environmentally friendly, and has a wide range of applications, but it has limitations such as low efficiency, deterioration of material performance, and inability to process lithium - iron phosphate batteries.

Chemical Method: It dissolves active substances with chemical solvents or acidic solutions to extract metals. It has advantages such as high recovery rate, strong flexibility, and environmental friendliness, but it has high costs, high energy consumption, and complex waste management.

Biological Method: It decomposes active substances with the catalytic action of microorganisms or enzymes. It has high environmental friendliness, low cost, and strong sustainability, but it has low efficiency, great technical challenges, and is mainly in the laboratory research stage at present.

Each of these three technologies has its own advantages and disadvantages. In practical applications, factors such as resource utilization, environmental impact, and economic benefits need to be comprehensively considered to promote the development of new energy vehicle battery recycling technologies and achieve the sustainable development of the industry.

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