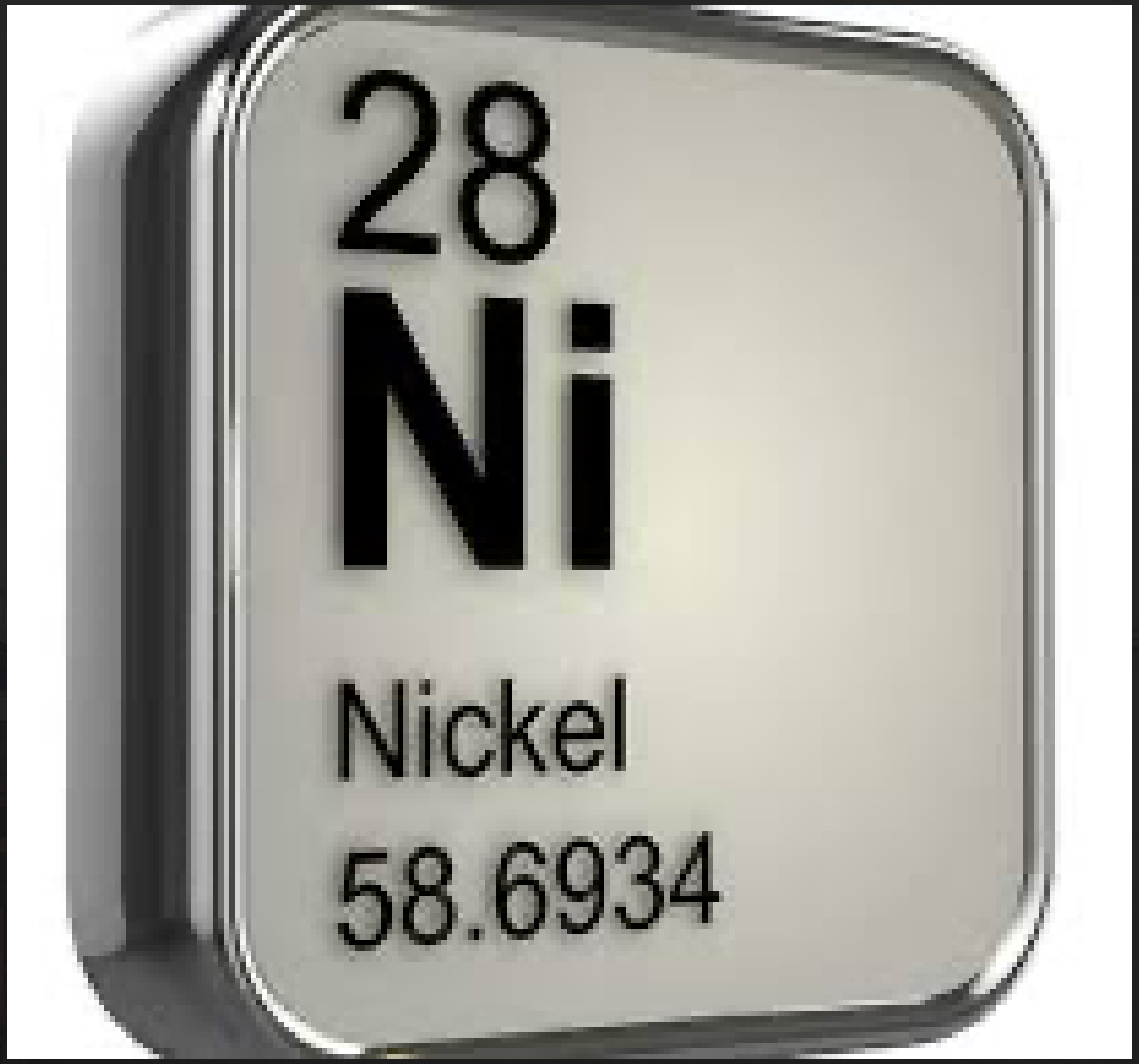
COST-EFFECTIVE RECOVERY OF

NICKEL

FROM WASTE BATTERIES



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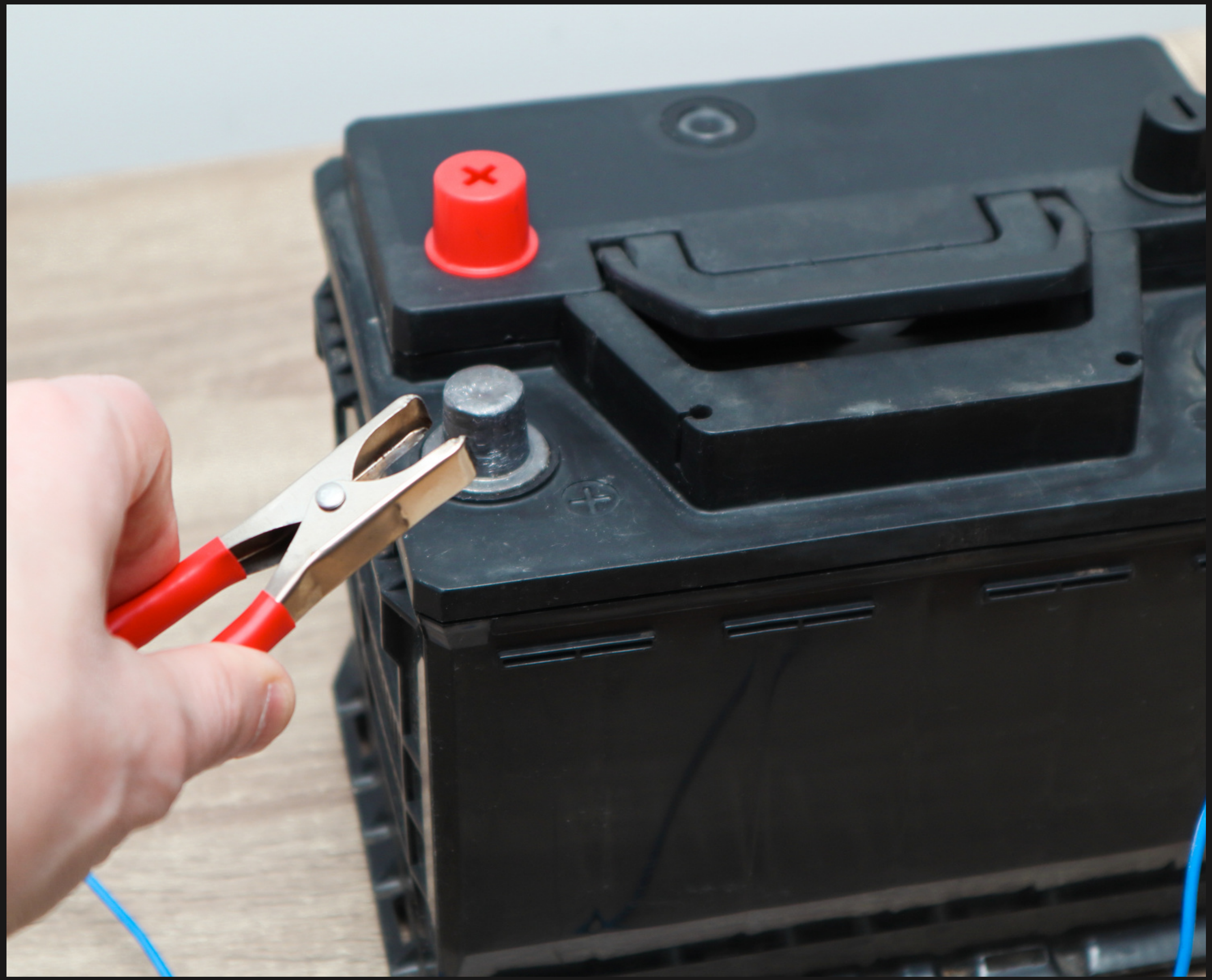


USAGE OF NICKEL IN BATTERIES

✓ **EARLY USE**

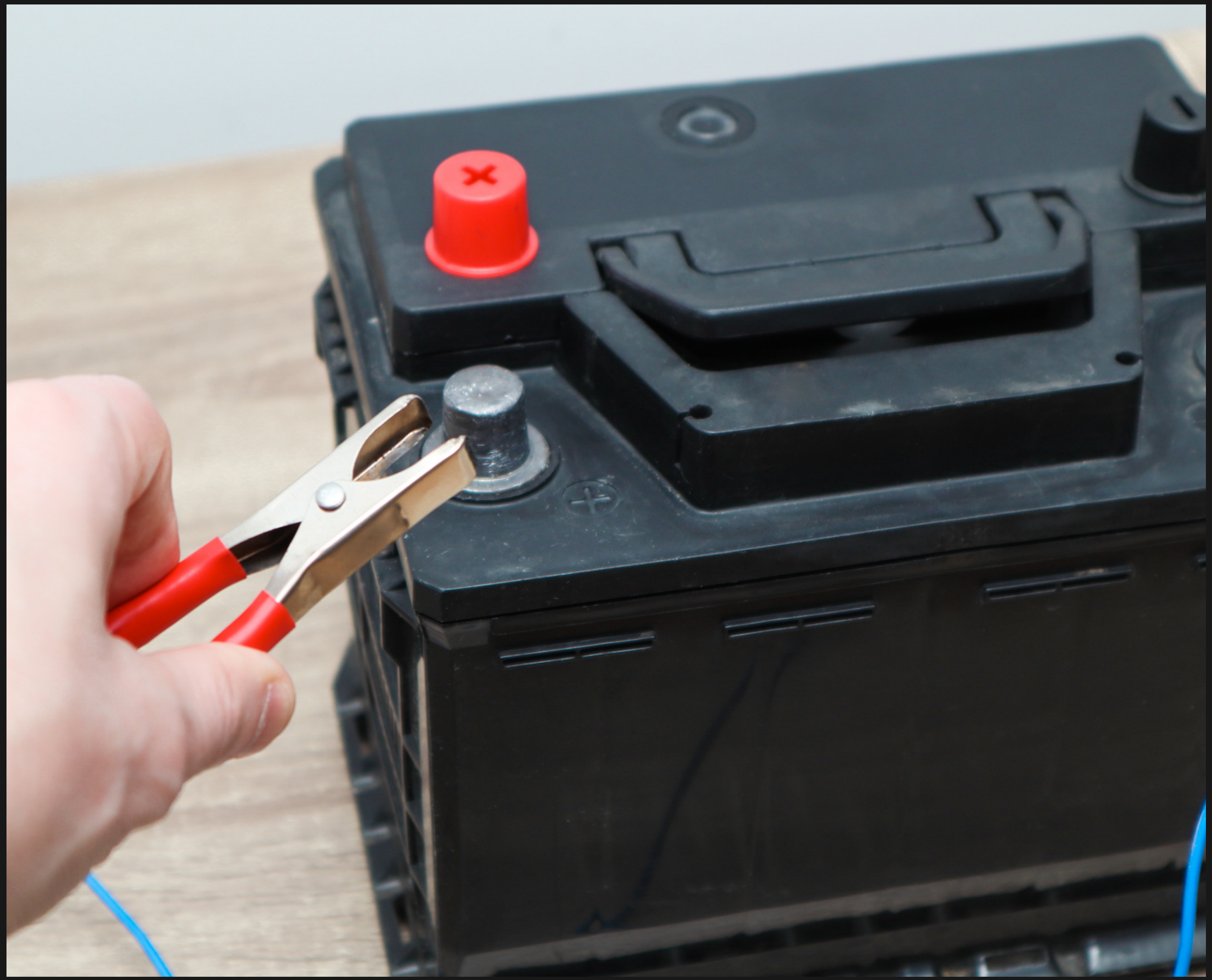
Nickel (Ni) has long been widely used in batteries, most commonly in nickel cadmium (NiCd) and in the longer-lasting nickel metal hydride (NiMH) rechargeable batteries

✓ **LI-ION BATTERIES**

Two of the most commonly-used types of batteries, Nickel Cobalt Aluminium (NCA) and Nickel Manganese Cobalt (NMC) use 80% and 33% nickel respectively; newer formulations of NMC are also approaching 80% nickel. Most Li-ion batteries now rely on nickel.

✓ **BENEFIT**

The major advantage of using nickel in batteries is that it helps deliver higher energy density and greater storage capacity at a lower cost.



IMPORTANCE OF NICKEL RECYCLING

SUSTAINABLE RESOURCE MANAGEMENT
Recycling nickel from waste batteries helps conserve natural resources and reduces the environmental impact of mining new nickel ores.

WASTE REDUCTION
Recovering nickel from batteries prevents these hazardous materials from ending up in landfills, where they can contaminate soil and groundwater.

ECONOMIC BENEFITS
Recovered nickel can be reused in new products, generating revenue and reducing reliance on costly imports of virgin nickel.

CURRENT CHALLENGES IN BATTERY RECYCLING

- ✓ In Nickel–cadmium (Ni-Cd) batteries, cadmium toxicity has resulted in a restriction in their overall use
- ✓ Nickel–metal hydride (Ni-MH) batteries are an improvement over Ni-Cd batteries while, at the same time, eliminating the use of toxic cadmium. However, this type of battery still faces challenges in terms of high cost, poor low-temperature performance, and high self-discharge.

OVERVIEW OF COST-EFFECTIVE RECOVERY TECHNIQUES

01

HYDROMETALLURGICAL PROCESSES

Leveraging acid or alkaline solutions to selectively extract and purify nickel from battery waste through leaching, precipitation, and electrochemical methods.

02

PYROMETALLURGICAL APPROACHES

Utilizing high-temperature smelting and refining techniques to recover nickel from battery scrap, often integrated with other metal recovery processes.

03

BIOLEACHING AND BIOSORPTION

Employing microorganisms to solubilize and concentrate nickel from waste, offering a green and sustainable alternative to conventional methods.

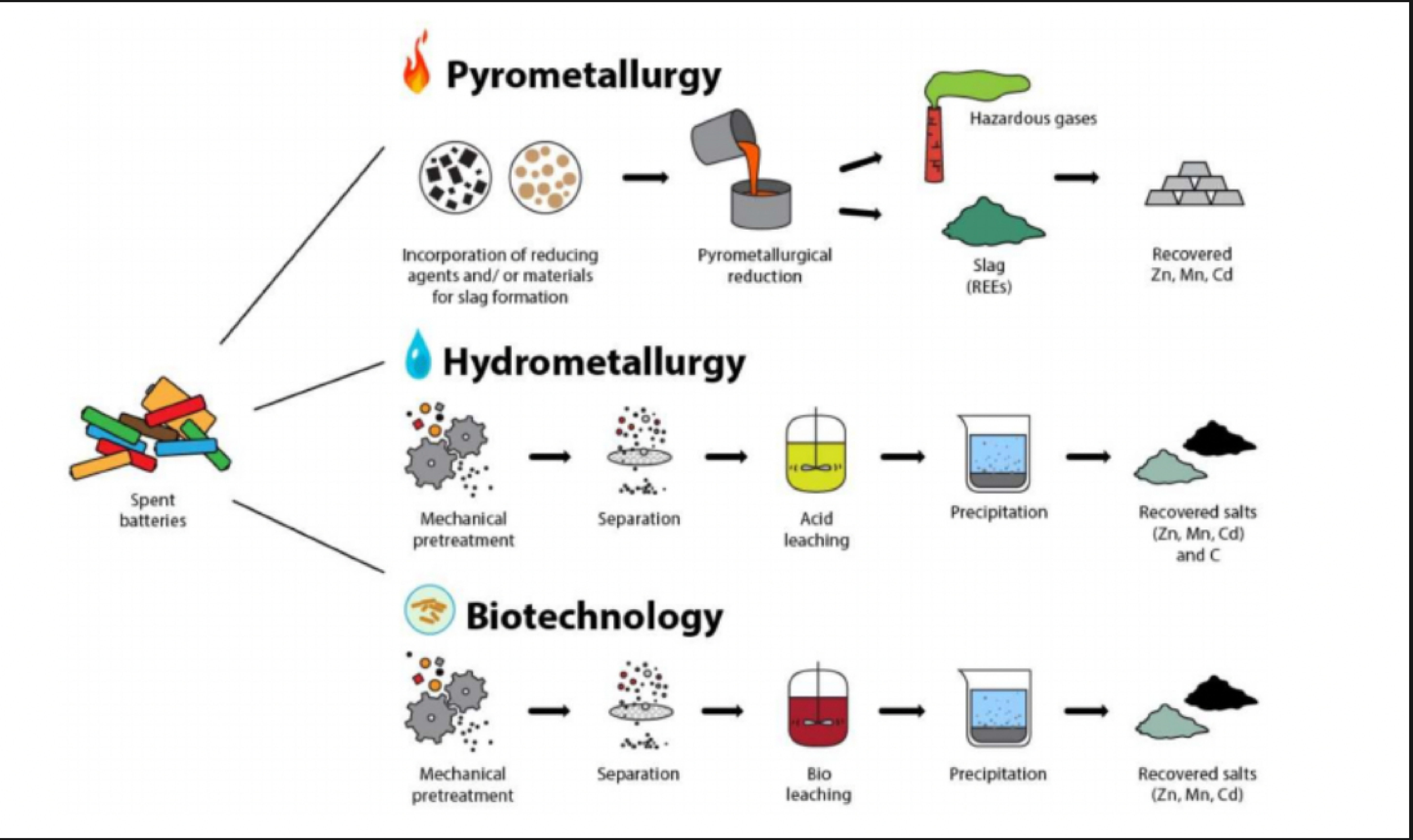
KEY STEPS IN RECOVERY PROCESS

01 Dismantling
Waste batteries are safely dismantled to extract the nickel-containing components.

02 Separation
The nickel-rich solution is separated from other metals through ion exchange or solvent extraction.

03 Leaching
The nickel-bearing materials are subjected to a mild acid leaching process.

04 Precipitation
The purified nickel solution is then subjected to precipitation to recover high-purity nickel.


Pyrometallurgy
Incorporation of reducing agents and/ or materials for slag formation
Pyrometallurgical reduction
Hazardous gases
Slag (REEs)
Recovered Zn, Mn, Cd
Spent batteries
Hydrometallurgy
Mechanical pretreatment
Separation
Acid leaching
Precipitation
Recovered salts (Zn, Mn, Cd) and C
Biotechnology
Mechanical pretreatment
Separation
Bio leaching
Precipitation
Recovered salts (Zn, Mn, Cd)

BATTERY COLLECTION AND DISMANTLING

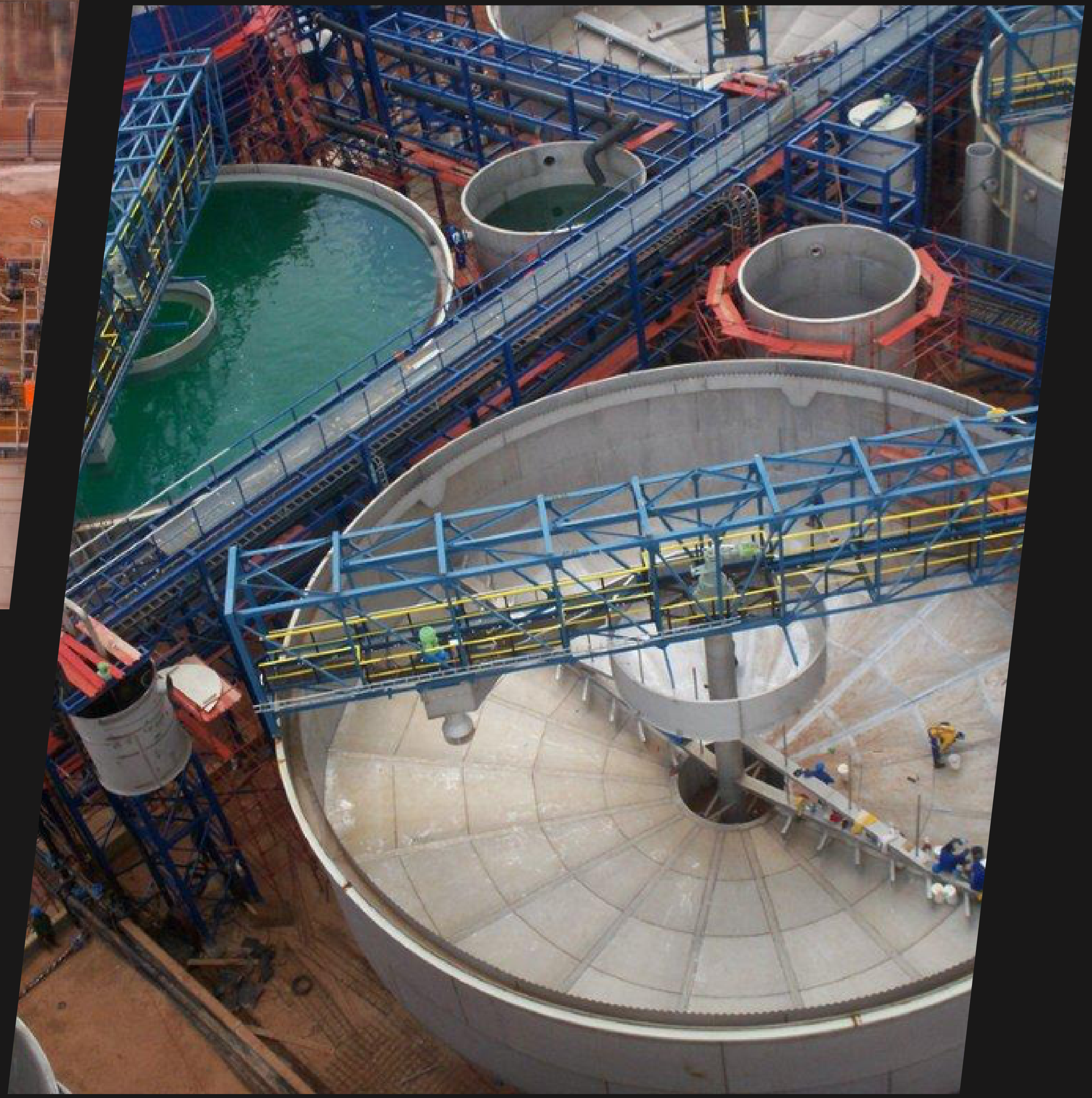
Manual dismantling and characterization involve the process of physically taking apart spent Ni-MH batteries by hand and then examining the separated components to understand their composition and properties.

Manual Dismantling:

- Batteries are carefully disassembled manually, typically by workers.
- Components such as electrodes, current collectors, plastic casings, and electrolytes are separated from each other.

Batteries were manually dismantled to classify its components. The electrodes were separated applying a mineral processing route during the manual dismantling and characterized by X-ray diffraction (XRD) analysis. A significant fraction of the batteries, around 37 wt.%, was Ni-based alloy. The spent batteries were treated using laboratory equipment. The overall metal yield was in the order of 86%.

HYDROMETALLURGICAL APPROACH TO NICKEL EXTRACTION



The hydrometallurgical approach offers a cost-effective and environmentally friendly method for recovering nickel from waste batteries. This process involves selectively leaching nickel from the battery materials using acidic or alkaline solutions, followed by precipitation and purification steps to produce high-purity nickel.

The key advantages of the hydrometallurgical route include its ability to operate at lower temperatures, reduced energy consumption, and potential for complete metal recovery with minimal waste generation.

SEPARATION

Low Temperature Processing:

- Suppresses chemical reactions to form a cake.
- Metal dissolution examined using sulfuric acid or alkali caustic solutions.
- Nickel recovery efficiency and purity > 94% on a weight basis.

Mechanical Separation:

- Individual materials (plastic, hydrogen, nickel) separated in a vacuum chamber.
- Output: product with high nickel content.
- Prevents hydrogen escape.

Hydrometallurgical Method:

- Dissolve electrode material in 2 M sulfuric acid at 95 °C.
- Rare earths recovered via solvent extraction circuit.
- Cobalt and nickel recovered as oxalate using oxalic acid.
- Overall cobalt and nickel recoveries: > 96% and 99.8% respectively.

Nickel Electrowinning:

- Problem: competing hydrogen reduction reaction reduces current efficiency.
- Results in curling and cracking of obtained metals.

Mechanical Separation Techniques:

- Physical separation based on size, shape, and density.
- Goal: separate metallic and non-metallic components.
- Can handle various battery types but may require further processing for metal refinement and purification

LEACHING

Leaching is a common hydrometallurgical process used in battery recycling. It involves the use of acid or alkaline solutions to dissolve metals from the battery materials.

- Acid leaching is employed to dissolve nickel compounds from the electrodes of the waste batteries.
- Commonly used acids for this purpose include sulfuric acid (H_2SO_4) or hydrochloric acid (HCl).
- Leaching can occur at ambient or elevated temperatures, depending on the specific battery chemistry.
-

The resulting leach solution is then subjected to purification and/or electroly-sis to recover individual metals. Acid leaching of Ni-Cd scrap using inorganic acids, like H_2SO_4, HCl, and HNO_3, ororganic acids, like citric acid, has been widely investigated. Over 95% Cd extraction can beachieved from Ni-Cd scraps at 100 ◦ C with 2.3–2.7 M H_2SO_4.

Recycling companies, like Umicore, have developed processes to recover REEs from NiMH batteries with up to 98% efficiency. The recycled REEs can be directly reused in newbatteries.

PRECIPITATION AND PURIFICATION TECHNIQUES

- Precipitation Techniques:
  - Add a reagent to the solution containing nickel ions.
  - Form a precipitate of nickel compound.
  - Common reagents include sodium hydroxide or ammonia.
  - Precipitate separated from the solution through filtration.

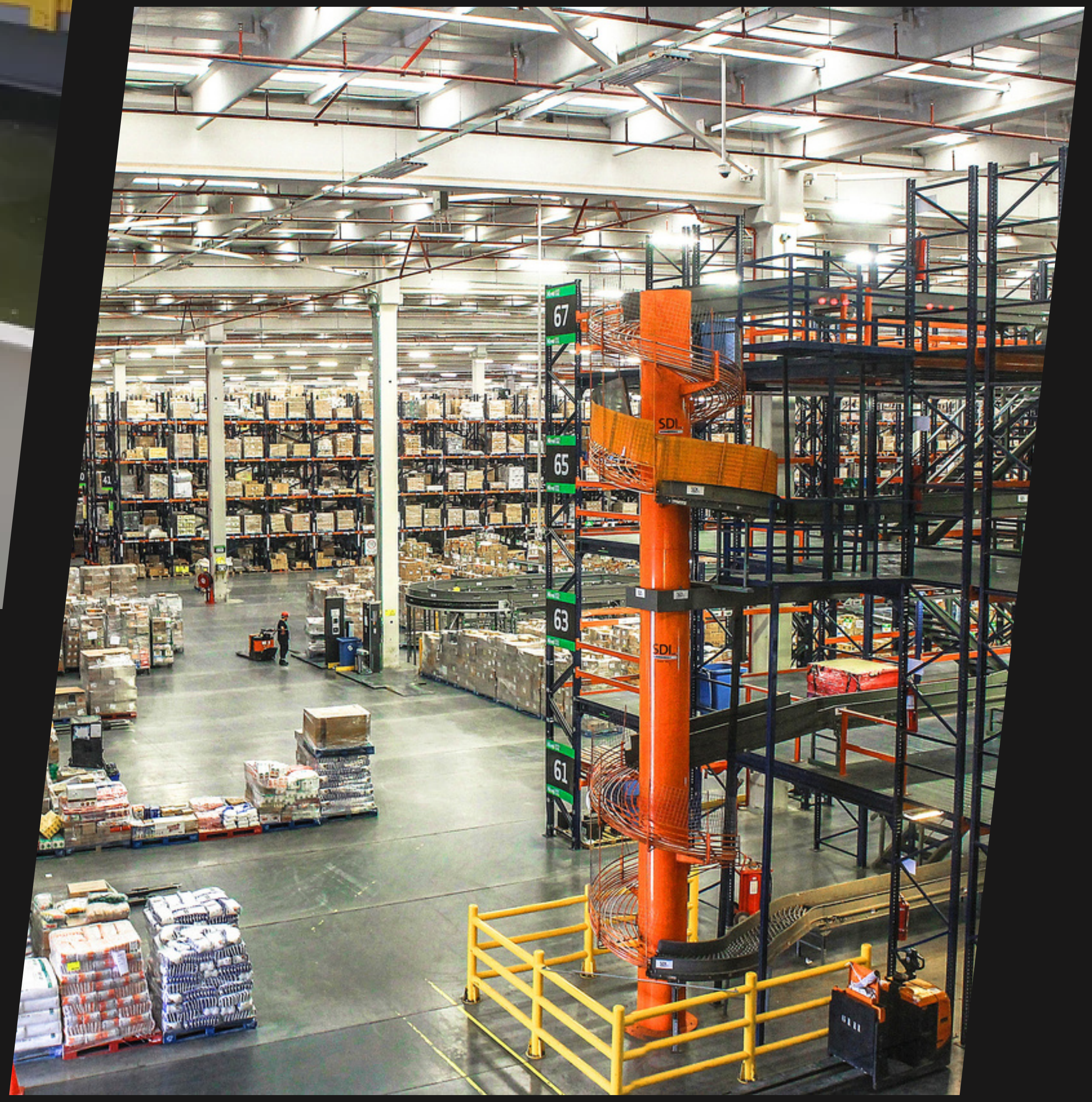
- Purification Techniques:
  - Refine the precipitated nickel compound to increase purity.
  - Techniques like solvent extraction or ion exchange may be employed.
  - Solvent extraction involves using organic solvents to selectively extract nickel ions from the solution.
  - Ion exchange utilizes resins or membranes to exchange ions, purifying the nickel solution.
  - Additional purification steps may include washing, drying, and calcination to obtain high-purity nickel metal.

OPTIMIZATION OF LEACHING AND PRECIPITATION PROCESSES

Optimizing the leaching and precipitation processes is crucial for cost-effective nickel recovery from waste batteries. This involves fine-tuning parameters like temperature, pH, and reagent concentrations to maximize nickel extraction and minimize waste generation.

Careful control of the precipitation step is also key, ensuring high-purity nickel compounds are selectively recovered while minimizing co-precipitation of impurities.

ADVANTAGES OF HYDROMETALLURGICAL NICKEL RECOVERY



The hydrometallurgical approach to nickel extraction offers several key advantages over conventional methods. It is a more environmentally-friendly process, reducing harmful emissions and waste byproducts. The selective leaching step allows for higher purity nickel recovery compared to pyrometallurgical techniques.

Hydrometallurgy also enables better resource utilization, as more of the nickel content in waste batteries can be recovered and recycled. The modular and scalable nature of hydrometallurgical plants allows for cost-effectiveimplementation, even for small-scale operations.

OVERVIEW OF THE DIFFERENT TECHNIQUES FOR NICKEL BATTERY RECYCLING

Battery Type	Recycling Technology	Advantages	Disadvantages
Alkaline, Ni-Cd, Ni-MH	Mechanical separation	Can handle diverse battery types and chemistries Separates metals from non-metals Scalable and flexible process	Does not recover pure metals Further refining steps needed Dismantling and size reduction required first
	Pyrometallurgy	Effective for large-scale metal recovery	High energy consumption Hazardous emissions Slag waste generation
Alkaline, Ni-Cd, Ni-MH	Hydrometallurgy	Selective metal recovery High purity products	Multi-stage, complex processes High reagent consumption Effluent treatment required
All Battery Types	Biotechnological Methods	Environmentally friendly Energy efficient Selective leaching	Early development stage Process optimization required
All Battery Types	Direct Recycling	Reduces processing steps Maintains material value	Limited commercial viability currently

TECHNOLOGICAL ADVANCES AND INNOVATION

- ✓ Enhanced Sorting and Collection Techniques Dual-energy X-ray transmission, spectroscopic techniques like laser-induced breakdown spectroscopy (LIBS), sensors like radio-frequency identification (RFID), tags on individual cells, improved disassembly methods.
- ✓ Advanced Battery Design for Recycling
- ✓ Automation and Robotics in Recycling Facilities
- ✓ Innovative Separation and Recovery Processes
- ✓ Circular Economy Approaches

FUTURE OUTLOOKS

- ✓ Improving Economics of Recycling Facilities
- ✓ Advancing Recycling Technologies
- ✓ Designing Future Batteries for Recycling
- ✓ Expanding Collection Networks
- ✓ Developing Recycling Policies
- ✓ Advancing Battery R&D

CONCLUSION

- Various separation processes, including low-temperature processing, mechanical separation, and hydrometallurgical methods, offer efficient ways to recover nickel from spent batteries.
- Each method has its advantages and limitations, addressing different aspects of the recycling process.
- Manual dismantling and characterization provide valuable insights into battery composition and aid in selecting appropriate recovery techniques.
- Precipitation and purification techniques further refine recovered nickel, ensuring high purity for subsequent use.
- Overall, the combination of these separation and purification processes offers a comprehensive approach to sustainable battery recycling, contributing to resource conservation and environmental protection

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