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# *Water-Related Environmental Impacts of Lithium-ion Battery Recycling and Decomposition*

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***Abstract.*** Lithium-ion batteries (LIBs) are indispensable for electric vehicles, consumer electronics, and renewable energy storage, yet their end-of-life management poses substantial threats to water systems. Improper disposal and informal processing of LIBs can release toxic metals (cobalt, and nickel, lithium) and persistent electrolyte compounds into groundwater and surface waters, posing ecological and human health risks. This paper reviews contamination pathways, including landfill leachate, acid leaching wastewater, and particulate emissions, and their impacts on fish, algae, and amphibians. Hydrometallurgical recycling, though highly efficient in material recovery, generates complex effluents needing treatment, whereas pyrometallurgical methods, while minimizing liquid waste, produce slag and airborne pollutants. Emerging techniques such as closed-loop hydrometallurgy, green solvents, bioleaching, and direct physical recycling show promise in reducing water-related impacts, especially when coupled with desalination and water reuse strategies. Aligning these advances with international policy frameworks, including the EU Battery Directive and U.S. EPA guidelines, is critical to achieving Sustainable Development Goal 6 (Clean Water and Sanitation). The paper contends that addressing LIB water impacts necessitates an interdisciplinary approach integrating hydrogeology, environmental chemistry, and sustainability science to build a circular economy that safeguards water resources while advancing the energy transition.

***Keywords:*** Lithium-ion Battery, Pollution, Environmental, Recycling, Sustainability

## 1. Introduction

With the widespread adoption of electric vehicles (EVs), consumer electronics, and renewable energy storage, the importance of lithium-ion batteries (LIBs) has become increasingly prominent. However, the end-of-life disposal of LIBs has emerged as a significant environmental issue, posing particular threats to aquatic ecosystems [1]. Water is fundamental to the survival and reproduction of all living organisms. Chemical pollutants released during LIB recycling can spread through the water cycle, potentially disrupting ecological balance, endangering health, and impacting biodiversity in both aquatic and terrestrial ecosystems [2]. From a geochemical standpoint, efficient LIB recycling is critical for closing metal cycles, preventing trace element leakage into hydrospheres, and sustaining planetary resource balances. Improper disposal of waste LIBs poses significant environmental risks due to their toxic constituents, including heavy metals (e.g., cobalt,

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nickel) and flammable electrolytes [3]. While existing research has examined LIB recycling technologies and environmental impacts, systematic studies on aquatic environments remain scarce. Comprehensive and in-depth analyses are particularly lacking regarding contamination pathways, the ecotoxicity of pollutants, and sustainable recycling strategies. Furthermore, existing research predominantly focuses on the efficiency and cost of individual recycling technologies, with insufficient comparative assessments of their combined effectiveness in mitigating water pollution [4-6].

This study centers on the aquatic environmental protection strategies. Employing a combined literature review and case study methodology, this work evaluates the aquatic environmental impacts of various recycling technologies—including pyrometallurgy, hydrometallurgy, direct physical recycling, and bioleaching—while analyzing their potential for water pollution reduction. Concurrently, it explores how technological innovation and policy support can advance Sustainable Development Goal 6 (Clean Water and Sanitation) within international policy frameworks [7, 8]. By elucidating the aquatic ecotoxicity of LIB recycling pathways, this research will empower evidence-based policymaking and catalyze circular economy transitions. By revealing pollution pathways and ecotoxicity, this research will support the development of effective aquatic environmental protection strategies, promote the circular economy, and contribute to achieving global clean water goals. Furthermore, it will guide future R&D directions for LIB recycling technologies and advance research in related fields.

## 2. Background

LIBs are usually composed of the cathode, the anode, the separator layer, the binder, the electrolyte, and organic solvents [8]. The anode is made up of graphite, which can store the lithium ions due to its structure, and the cathode is made up of lithium metal oxide. The electrolyte is lithium salt, and the separator is made up of polypropylene, which needs to have microporosity so that the lithium ions can pass through. Since electrons cannot flow freely within the battery, metal foils (such as aluminum and copper) are used as conductors to ensure consistent electron movement. All these materials compressed to contact electricity successfully(as depicted in Figure. 1) [9].

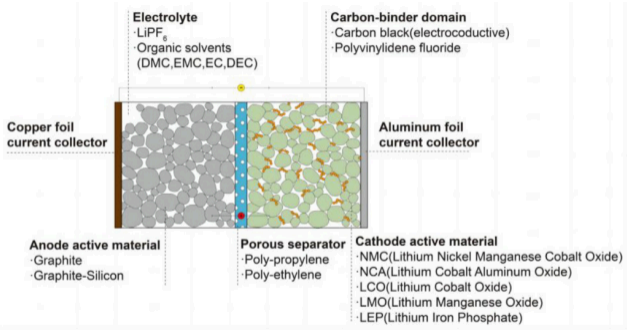



**Fig. 2.** An illustration of different components for LIBs with different chemistries.

Figure 1. An illustration of different components for LIBs with different chemistries [10]

The recycling processes of LIBs are generally categorized into chemical and physical methods [11]. Pretreatment is the critical first step in safe LIB recycling, requiring complete discharge to eliminate residual energy (preventing thermal runaway), followed by automated dismantling, mechanical crushing, and component sorting. A combined pyrolysis-ultrasonic treatment enables

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efficient separation of aluminum/copper current collectors from active materials, providing high-quality feedstock for subsequent metal extraction processes [11].

Pyrometallurgy is commercialized (e.g., Umicore's shaft furnace process) for Co recovery. It heats LIBs to smelt valuable metals into alloys (Co, Ni, Cu) but loses Li to slag, consumes high energy, and emits hazardous gases (dioxins) [11]. Hydrometallurgy, the most extensively researched method, uses acids (inorganic: HCl, $H_2SO_4$; organic: citric acid) or microorganisms (bioleaching) to extract metals from electrodes. It achieves high recovery rates (e.g., >99% Co/Li with HCl) and can recover Li, but requires toxic reagents, generates waste acid sludge, and is rarely commercialized due to high treatment costs [11].

Direct physical recycling is an eco-friendly option that extracts electrolytes (via supercritical $CO_2$) and reuses electrode materials (with minor relithiation or heat treatment). It has low energy consumption but is limited by inconsistent performance of recycled materials (e.g., reduced capacity retention vs. fresh electrodes) [11]. There are four main methods to dispose of waste LIBs, including recycling, landfilling, illegal disposal, and informal processing. The two different types of batteries need to be treated through different techniques, respectively. While large batteries are generally retired from EVs, their condition is often difficult to assess, especially given the risk of explosions during transportation, landfilling, storage, or recycling. For the small one, it may be typically thrown to the rubbish bin, which is not the correct bin to put it in by the consumer, which results in damaging fires during transportation or in material recovery facilities (MRFs) [12].

## 3. Pathways of water contamination

Lithium-ion batteries typically contain 5-20% cobalt (Co), 5-10% nickel (Ni), 5-7% lithium (Li), 15% organic compounds, and 7% plastic, with the exact composition determined by the manufacturer [3].

### 3.1. Heavy metal migration

Heavy metal migration, particularly of lithium and cobalt, represents a major pathway of water pollution and poses significant risks to aquatic ecosystems. In the forearc of subduction zones, Lithium is also added to seawater in fluids expelled and indicated that the total annual flux of dissolved lithium into the world's oceans ranges from $126\times10^9$ to $175\times10^9$ g. This data indicates that the input of lithium into the world's oceans far exceeds its known natural deposition. Stoffyn-Egli and MacKenzie were the first to observe that this input surpasses the capacity of identified sinks. They suggested that lithium incorporation into authigenic clay minerals in marine sediments could explain this imbalance — a process now known as reverse weathering. Then, the independent evidence showed in soils, rivers and marine sediments, the formation of secondary clay minerals with preferential incorporation of Lithium isotope 6 [13].

Of the total lithium deposited in oceanic sediments, an estimated $51–58\times10^9$ g/year is transported into subduction zones, while the remainder is retained within sedimentary sequences along passive continental margins. The subducted flux values are derived by combining estimates of the global mass of subducted sediments—ranging from $11.3\times10^{15}$ g/year to $13\times10^{15}$g/year—with the average lithium concentration in these sediments [14]. Earlier calculations placed the lithium flux into subduction zones at approximately 38 $\times10^9$g/year. Collectively, these estimates align with the broader observation that about 10% of marine sediments undergo subduction, whereas the majority accumulate along passive margins [13,15]. Wastewater is typically generated during discharge pretreatment and cathode material recovery processes. The pollutant reacted with the substance in

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the wastewater to generate the salt sodium sulfate and a few organic contents. In contrast, effluents produced during the acid leaching and solvent extraction stages present a more complex profile, containing lithium cobalt oxide, lithium iron phosphate, methylpyridinium alkanone, ultrafine carbon powder, and low-molecular-weight esters. Although the wastewater volume is relatively small, its chemical complexity, low biodegradability, and inherent toxicity present significant treatment challenges. To address these issues, desalination is generally achieved through triple-effect evaporation or mechanical vapor recompression (MVR) evaporators. The treated effluent can subsequently be reused as pulping water, thereby eliminating direct discharge into the environment.

### 3.2. Release of pollutants

The dissolution of battery components represents a major mechanism for aquatic contamination. Leaching—defined as solute extraction from solids using liquid solvents—is particularly challenging for $LiCoO_2$ cathodes due to their limited solubility in conventional agents. Consequently, spent LIB recycling predominantly employs strong inorganic acids ($H_2SO_4$, HCl, $HNO_3$) for $LiCoO_2$ recovery. Comparative studies have evaluated leaching agents including sulfurous acid, hydroxylamine hydrochloride, and hydrochloric acid for their dissolution efficiency [3]. Mechanical processing, primarily shredding during disassembly, generates particulate emissions that endanger both recycling facility workers and nearby communities. Furthermore, LIB-derived heavy metals exert toxicity by binding to and disrupting biomolecules such as carbohydrates, proteins, and enzymes [9].

## 4. Impacts on aquatic environments

Having explored the pathways through which lithium-ion batteries can contaminate water sources, it is crucial to delve into the impacts these contaminants have on aquatic environments. Aquatic ecosystems are vulnerable to Li pollution (from industrial runoff, battery waste, or mineral water discharge), with toxicity varying by species, exposure duration, and water chemistry.

Fish are particularly susceptible to lithium pollution, with varying sensitivity across species. Juvenile rainbow trout show a 10-day Lowest Observed Effect Concentration (LOEC) of 0.6 mg/L, with mortality linked to gill damage and electrolyte imbalance, indicating significant gill damage and electrolyte imbalance at low lithium concentrations. Pimephales promelas (fathead minnow) exhibits $LC_{50}$ of 1.2–8.7 mg/L after 26 days of exposure, with long-term effects including reduced growth and abnormal swimming behavior. Li disrupts embryonic development: Fundulus heteroclitus (mummichog) embryos exposed to 1.7 mg/L Li show delayed hatching and malformations (e.g., curved spines) [16,17].

Lithium stress triggers neurotoxin production in marine algae. The diatom Pseudo-nitzschia multiseries significantly increases domoic acid secretion under Li exposure, creating trophic transfer risks to shellfish and human consumers. Amphibian embryos display severe developmental anomalies: Rana pipiens (leopard frog) and Ambystoma tigrinum (tiger salamander) develop microcephaly and neural tube defects when exposed during early segmentation. Mechanistically, Li interferes with plasma membrane protein function, disrupting cell migration and tissue morphogenesis [16,17].

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## 5. Sustainability and water resource protection

SDG 6 of the United Nations 2030 Agenda for Sustainable Development aims to "ensure availability and sustainable management of water and sanitation for all." However, improper disposal of waste lithium-ion batteries (LIBs) poses a significant challenge to achieving this goal. Heavy metals (e.g., cobalt, nickel, and manganese) and lithium salts in LIBs contaminate groundwater, surface water, and wastewater streams, disrupting aquatic ecosystems and posing risks to human health through bioaccumulation. Experimental evidence shows that LCO nanoparticles induce cellular oxidative stress by triggering reactive oxygen species (ROS) overproduction, resulting in DNA and protein damage [7, 8].

Closed-loop hydrometallurgical systems mitigate wastewater generation through solvent recovery and leaching agent recycling, effectively reducing COD and TDS concentrations. Green solvents—such as deep eutectic solvents (DESs) and ionic liquids—replace strong mineral acids, diminishing wastewater contamination. Bioleaching technologies further reduce recovery process emissions by utilizing metal-tolerant microorganisms [7,8]. Evolving policy frameworks, such as the EU Battery Directive and U.S. EPA guidelines, support these technologies' adoption. However, future policy frameworks must be strengthened to ensure sustainable battery recycling practices. Circular economy principles and interdisciplinary collaboration are key to achieving SDG 6, requiring integration of hydrogeology, environmental chemistry, and sustainability science to protect water resources and support the energy transition.

## 6. Discussion

Among LIB-derived pollutants, cobalt stands out as a critical contaminant due to its environmental persistence, acid-enhanced mobility, and severe ecotoxicological effects, including bioaccumulation in aquatic food chains and human health risks. Cobalt ions interfere with enzymatic functions and can induce oxidative stress, which makes even low concentrations problematic for water quality and ecosystem stability [10]. Nickel and manganese also contribute to long-term groundwater contamination, though their toxicological profiles are somewhat less severe than cobalt's. Although lithium is traditionally viewed as less toxic, its high solubility in water enables widespread ionic disruption in freshwater ecosystems, posing emerging risks to species reliant on stable osmotic gradients. More recently, attention has shifted to organic electrolyte degradation products, some of which share persistence and mobility traits with per- and polyfluoroalkyl substances (PFAS). These PFAS-like compounds resist natural attenuation, accumulate in water systems, and complicate conventional treatment processes, raising concerns about chronic exposure risks that extend beyond metals. Although pyrometallurgy appears to have lower direct water impacts, its indirect contributions to water contamination and its high energy intensity make hydrometallurgy—with proper safeguards—the more sustainable option [10].

Ultimately, addressing LIB-related water impacts demands an interdisciplinary research approach. Hydrogeological modeling is indispensable for mapping contaminant migration through subsurface layers, whereas environmental analytical chemistry enables the structural elucidation and fate tracking of emerging organic pollutants in hydrological systems. Sustainability science integrates these findings into policy and industrial practice, ensuring that technological advances align with global clean water goals under SDG 6 [8].

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## 7. Conclusion

The exponential growth of lithium-ion battery (LIB) adoption necessitates urgent, sustainable water resource management strategies to mitigate emerging contamination risks. Evidence from ecotoxicological studies confirms that cobalt, nickel, and emerging PFAS-like electrolyte compounds represent the most pressing contaminants due to their persistence, bioaccumulation potential, and toxicity at low concentrations. Current recycling practices illustrate a tension between recovery efficiency and environmental protection: while pyrometallurgy produces fewer direct wastewater streams, its indirect impacts and high energy use limit long-term sustainability; conversely, hydrometallurgy offers higher recovery rates but risks generating hazardous effluents if not carefully controlled. Innovations such as closed-loop hydrometallurgy, solvent systems with lower environmental footprints, and direct electrode reuse provide a pathway to reconcile resource recovery with water protection. Crucially, regulatory frameworks—including the EU Battery Directive and U.S. EPA guidelines—can accelerate the adoption of these low-impact technologies, ensuring that battery recycling aligns with the targets of UN SDG 6. Yet technology alone is insufficient. A holistic defense against LIB pollution demands integrated expertise—from hydrogeologists mapping contaminant plumes to chemists designing biodegradable electrolytes—coupled with robust knowledge transfer between academia and industry.

## References

[1] Summaries, M. C. (2021). Mineral commodity summaries. US Geological Survey: Reston, VA, USA, 200.
[2] Kılıç, Z. (2020). The importance of water and conscious use of water. International Journal of Hydrology, 4(5), 239-241.
[3] Ordoñez, J., Gago, E. J., & Girard, A. (2016). Processes and technologies for the recycling and recovery of spent lithium-ion batteries. Renewable and Sustainable Energy Reviews, 60, 195-205.
[4] Yang, X., Zhang, H., Liu, Q., & Jiang, G. (2025). The Li-ion battery industry and its challenges. Nature Reviews Chemistry, 1-2.
[5] Blair, J. J., Vineyard, N., Mulvaney, D., Cantor, A., Sharbat, A., Berry, K., ... & Ornelas, A. F. (2024). Lithium and water: Hydrosocial impacts across the life cycle of energy storage. Wiley Interdisciplinary Reviews: Water, 11(6), e1748
[6] Moran, B. J., Boutt, D. F., McKnight, S. V., Jenckes, J., Munk, L. A., Corkran, D., & Kirshen, A. (2022). Relic groundwater and prolonged drought confound interpretations of water sustainability and lithium extraction in arid lands. Earth's Future, 10(7), e2021EF002555.
[7] Makanda, K., Nzama, S., & Kanyerere, T. (2022). Assessing the role of water resources protection practice for sustainable water resources management: A review. Water, 14(19), 3153.
[8] Abu-Zeid, M. A. (1998). Water and sustainable development: the vision for world water, life and the environment. Water policy, 1(1), 9-19.
[9] Xiaodong, S., & Ishchenko, V. (2024). Environmental impact analysis of waste lithium-ion battery cathode recycling. Journal of Ecological Engineering. 25 (7): 352-358.
[10] Guo, R., Wang, F., Rhamdhani, M. A., Xu, Y., & Shen, W. (2024). Managing the surge: A comprehensive review of the entire disposal framework for retired lithium-ion batteries from electric vehicles. Journal of Energy Chemistry, 92, 648-680.
[11] Huang, B., Pan, Z., Su, X., & An, L. (2018). Recycling of lithium-ion batteries: Recent advances and perspectives. Journal of power sources, 399, 274-286.
[12] Mrozik, W., Rajaeifar, M. A., Heidrich, O., & Christensen, P. (2021). Environmental impacts, pollution sources and pathways of spent lithium-ion batteries. Energy & Environmental Science, 14(12), 6099-6121.
[13] Schlesinger, W. H., Klein, E. M., Wang, Z., & Vengosh, A. (2021). Global biogeochemical cycle of lithium.
[14] Plank, T. (2014). The chemical composition of subducting sediments. Elsevier.
[15] Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C., & Daily, G. C. (2006). Conservation planning for ecosystem services. PLoS biology, 4(11), e379.

DOI: 10.54254/2755-2721/2026.KA28357

[16] Sobolev, O. I., Gutyj, B. V., Darmohray, L. M., Sobolieva, S. V., Ivanina, V. V., Kuzmenko, O. A., ... & Chernyuk, S. V. (2019). Lithium in the natural environment and its migration in the trophic chain. Ukrainian Journal of Ecology, 9(2), 195-203.
[17] Shahzad, B., Mughal, M. N., Tanveer, M., Gupta, D., & Abbas, G. (2017). Is lithium biologically an important or toxic element to living organisms? An overview. Environmental Science and Pollution Research, 24(1), 103-115.