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# Navigating the High Costs of Energy Storage: Challenges and Solutions for Sustainable Integration

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***Abstract:*** As global energy consumption continues to rise, it is imperative that energy supply systems are aligned to meet this growing demand. However, the current state of the energy industry is characterized by prohibitively high costs associated with energy storage systems, alongside significant inefficiencies and energy wastage. This paper first introduce two main energy storage system: Lithium-ion battery, Compressed Air Energy Storage(CAES), explores the underlying factors contributing to these elevated costs and examines the current energy landscapes of key regions, including Asian countries, particularly China, the United States, and Europe. Through a comparative analysis, the paper identifies the differences and underlying causes that drive these disparities. Furthermore, it proposes strategic solutions to address these cost challenges, such as reforming tax systems to incentivize innovation, enhancing supply chain efficiency through better integration and localization, and investing in research and development to drive technological advancements. By tackling these issues, the global energy sector can advance towards more cost-effective and sustainable energy storage solutions, thereby supporting the transition to a low-carbon future and ensuring energy security for generations to come.

***Keywords:*** Lithium-ion battery, Compressed Air Energy Storage(CAES), Supply chain complexity.

## 1. Introduction

Energy storage contributes a significant role in preserving energy, balancing supply and demand, and further enhancing grid stability. With the increasing integration of renewable energy sources, especially solar and wind energy, which high lightened significance of energy preservation. As countries meet the demand and target for renewable energy, there is a need to balance supply and demand for those energy [1]. The demand for key materials, such as lithium and cobalt surged due to their essential roles in battery production. This increased demand can lead to supply shortages, driving up prices, consequently lead to the costs increased of energy storage technologies. Therefore, it is critical to have an advanced energy storage system with enough efficiency but low costs, to ensure the stability supply and transformation is unobstructed. However, in the current environment of energy storage method, there is a rigid circumstance that the storage costs are significantly high. As of 2021, global installed energy storage capacity reached approximately 30 gigawatts (GW), with projections suggesting it could grow to 200 GW by 2030. This growth is driven by increasing demand for renewable energy integration and grid stability. The Lazard Levelized Cost of Storage Analysis

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indicated that the LCOS for lithium-ion batteries ranges from $150 to $300 per megawatt-hour (MWh) [2]. The average maintaining cost of a 50 MW battery storage system ranges from $500,000 to $1 million [3]. This cost can be prohibitive compared to traditional energy sources, depending on local conditions. With a higher demand for energy consumption, the costs will be much higher with the increasing trend predicted.

## 2. Literature Review

The current state of high energy storage system is a general landscape in the energy industry. In order to figure out the factors driving the high costs and propose some possible solutions responding to urgent landscape, the paper first analysis the current environment of energy storage system combining data. The production cost involves cobalt and lithium, lithium is extremely expensive in manufacturing and operating energy storage systems. Zakeri & Syri, 2015 highlight that material scarcity and geopolitical factors can drive up costs [4]. Secondly, the complexity of manufacturing processes and the need for specialized equipment contribute to high production costs [5]. Additionally, supply chain disruptions can lead to price volatility. Moreover, the regulatory frameworks often lag behind technological advancements, creating uncertainty and discouraging investment.

Trying to address the problems of high costs, Harper, 2019 proposed to develop effective recycling processes that can reduce material costs and mitigate environmental impacts [6]. Moreover, from current regulation system, government as a main regulator in policies and political issues, introducing new taxes system can be an effective way to address the potential high costs while using correct way to deduct, especially in some specific regions.

## 3. Energy Storage Technology System

There are various energy storage technologies that exist in the current market which EASE organizes in 5 energy storage classes: chemical, electrochemical, electrical, mechanical and thermal. The two types chosen from various as two representatives, Lithium-ion battery and Compressed Air Energy Storage System ranging at a different operating price. Represent the current environment of energy storage system.

### 3.1. Lithium-ion Batteries

Lithium-ion batteries are at the forefront of energy storage technology, primarily due to the high energy density and versatility across various applications, including electric vehicles (EVs), renewable energy systems, and portable electronics. Despite their advantages, the costs associated with lithium-ion batteries remain a critical concern. As reported by the U.S. Department of Energy, the average cost of lithium-ion battery systems ranges from $200 to $300 per kilowatt-hour (kWh) [7], which reflects not only the materials and manufacturing processes but also the supply chain complexities involved in sourcing lithium and cobalt.

The high cost of lithium-ion batteries can be attributed to several factors: the reliance on rare and geographically concentrated materials, the energy-intensive manufacturing processes, and the environmental implications of mining and processing these materials. Additionally, while significant advancements have been made to reduce battery costs over the last decade, the volatility in the prices of raw materials can lead to unpredictable fluctuations in overall battery prices. This presents a barrier to the scalability of applications such as grid storage and EVs, which are crucial for the transition to a low-carbon economy.

Moreover, the implications of high costs extend beyond financial considerations; they influence market dynamics and consumer adoption. For instance, the elevated costs of lithium-ion batteries can deter potential investors and limit the accessibility of EV technology to a broader audience, thereby

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slowing the shift toward sustainable transportation. Furthermore, the environmental impact associated with battery production and disposal raises additional concerns, necessitating a comprehensive approach to recycling and lifecycle management to mitigate these challenges.

### 3.2. Compressed Air Energy Storage(CAES)

Compressed air energy storage (CAES) offers an alternative approach to energy storage, utilizing compressed air to store and later generate electricity. While CAES systems can provide substantial storage capacities and are particularly well-suited for long-duration energy storage, the high initial capital costs associated with the construction of CAES facilities present significant hurdles. Establishing CAES requires extensive infrastructure, including suitable geological formations for underground storage, which can limit deployment options and increase project costs.

The economic feasibility of CAES is further complicated by efficiency losses during the compression and expansion processes, which can diminish the overall effectiveness of the system. According to industry analyses, the round-trip efficiency of CAES systems typically ranges from 60% to 75%, meaning a portion of the energy input is lost during the storage and retrieval processes. This inefficiency, combined with high setup costs, can make CAES less competitive compared to other energy storage technologies, especially in markets where rapid response times and lower capital investments are prioritized.

However, the long-term potential of CAES should not be overlooked. As the need for large-scale energy storage solutions grows in tandem with the increasing penetration of renewable energy sources into the grid, CAES can play a crucial role in providing grid stability and load balancing. Policymakers and industry stakeholders must consider innovative financing models, technological advancements, and strategic partnerships to address the high costs associated with CAES, thereby unlocking its potential as a viable energy storage solution

## 4. Factor Contributed

There are three factors that lay behind a potential of high energy storage costs.

### 4.1. Raw Material Price

In constructing energy storage system, the components to construct the storage system are high. The material cost of other electrochemical storage technologies is driven by active materials like platinum, lithium, and lead. Lithium ion is a family of technologies with different options for materials used in the cathode. Taking average raw material cost, NMC is 66% more expensive than LFP. Mechanical storage technologies have the lowest material cost below 20 USD/kWh due to the low-cost materials employed [8]. Table 1 listed the costs of five different type of technology, in which, Vanadium- Flow have a highest raw material price.

Table 1: Comparative price for raw material costs

| Technology | Raw material cost | Key costs driver |
|---|---|---|
| Nickel-Metal Hydride | $250 | High nickel prices |
| Vanadium-Flow | $400 | Volatile vanadium prices |
| Lithium-Ion (NMC) | Approx. $130-$200 | Lithium, nickel, cobalt |
| Lithium-Ion (LFP) | Approx. $80-$120 | Lithium, iron |
| Mechanical Storage | < $20 | Low-cost materials |

As the second main contributor of raw material, Cobalt, geographical location as a factor contributes to it high price of raw material cost. The Democratic Republic of the Congo (DRC) is the world's largest producer of cobalt, accounting for approximately 70% of global supply [9]. The current landscape exists of instable environment of political, infrastructure challenges, corruption and government issues. DRC experienced multiple civil wars since the late 1990s, resulting in widespread violence and instability. Various armed groups operate in mining regions, often controlling mines and extorting miners. This situation can disrupt mining operations and lead to sudden supply shortages. Government as a regulator, controlling the regulation, bribery and mismanagement can lead to inconsistent enforcement of mining laws, impacting both large mining companies and artisanal miners. This corruption can deter foreign investment and lead to a lack of infrastructure development, further hampering production capabilities. Inconvenient traffic leads to a higher raw material cost, the rail network in the DRC is often in disrepair, with many lines not adequately maintained. This leads to frequent delays and interruptions in service, making rail transport an unreliable option for moving goods, including cobalt from mining sites to ports.

### 4.2. Manufacturer Complexity

The complexity in the manufacturing process contributes to a high cost related making process. The intricate processes involved in battery manufacturing require a significant number of investments in advanced machinery and technology. Equipment for coating, drying, and precision assembly can be costly, often reaching millions of dollars for a fully operational plant. This high capital expenditure (CapEx) must be recouped through the pricing of the final products, contributing to higher costs for consumers. The electrode fabrication process involved manufacture, slurry preparation, coating process, drying and compression. The electrode foils are coated with the slurry to a thickness typically 50-100 micrometers. Variations outside this specific range will lead to inefficiencies, impacting energy density. Automated coating machines range from “$200,000 to over $1 million”, with additional costs for maintenance and operations [10]. Additionally, the drying and compression processes require significant energy input. Also, the need for controlled environments during fabrication (e.g. cleanroom conditions) further adds to energy consumption and operational costs. Each batch of electrodes must undergo stringent quality control measures to ensure they meet performance standards. Includes testing for thickness, uniformity, and adhesion properties. Each tiny process within the fabrication requires accurate consideration and measures, these precisions require advanced machinery to control. High-quality lithium-ion batteries are expected to achieve more than 2,000 cycles at 80% depth of discharge. Testing cycles can take several months, and the cost of testing equipment can range from $50,000 to $200,000. Manufacturers often maintain multiple testing units to expedite this process. The acceptable defect rate in high-quality batteries is often below 1%. However, achieving this requires extensive monitoring and control of production processes, which can add significant operational costs. For example, implementing real-time monitoring systems can add an extra $300,000 to $500,000 in capital expenditure [10].

### 4.3. Research and Development

The development of new battery technologies requires thorough performance testing to evaluate critical parameters such as energy density, cycle life, charge/discharge rates, and thermal stability. For instance, a typical lithium-ion battery cell may undergo thousands of charge-discharge cycles to assess its lifecycle performance, which can take several months to complete. According to research conducted by the U.S. Department of Energy, battery testing can consume up to 30% of the total R&D budget due to the extensive time and resources required. Moreover, performance testing often

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involves multiple stages, including initial lab-scale tests followed by larger-scale evaluations. Each stage demands specific setups, equipment, and materials, which can incur substantial costs.

R&D in energy storage is inherently iterative, with initial prototypes undergoing multiple rounds of testing and refinement. Each iteration not only requires new materials and testing setups but also necessitates incorporating feedback and making design modifications. This iterative process can prolong development timelines and escalate costs, as manufacturers must repeatedly allocate resources for both the development and testing of revised prototypes. For instance, if a new battery design requires three to four iterations of testing before reaching commercial viability, the cumulative costs of materials, labor, and testing can significantly exceed initial projections

## 5. Comparative Analysis

On a regional basis, average battery pack prices were lowest in China, at $126/kWh. Packs in the US and Europe were 11% and 20% higher, respectively [11]. Higher price in other two regions reflect the relative immaturity of markets within the countries. Higher production costs, lower volumes, and the diverse range of applications will occur. There was also intense price competition domestically in China this year as battery manufacturers ramped up production capacity aiming to grab a share of the growing battery demand.

In the Asia-Pacific region, particularly in China, the estimated cost of lithium-ion battery storage has reached approximately $100to $300 per kilowatt-hour (kWh), declined to $94 in 2024. This price point is primarily driven by large-scale manufacturing capabilities and government support, enabling companies to capitalize on economies of scale. According to the International Energy Agency (IEA), China accounted for over 85% of global battery production in 2023, significantly lowering costs through mass production efficiencies [11]. For CATL, the company held 32.5% share of lithium-ion battery market, according to SNE Research, large scale of production lead to cost reductions due to economic of scale [12]. Further analysis reveals that China's dominance in the supply chain extends beyond production; it also encompasses the extraction and processing of critical raw materials. For instance, China controls a significant portion of global lithium processing, which not only reduces costs but also enhances supply chain resilience. This vertical integration allows Chinese manufacturers to mitigate price volatility in raw materials, further solidifying their competitive edge. Moreover, as China possesses significant supply chain of raw materials, Chinese domestic processing capacity for these raw materials is unparalleled. Developed extensive facilities domestically used to refine and process lithium and other essential minerals, which allows it to convert raw materials into battery-grade components efficiently, without the reliance to other countries in manufacturing process.

Compared to United States, the U.S. market faces unique challenges, including supply chain disruptions and higher labor costs, which can offset some of the benefits derived from economies of scale, but the economics of scale benefits is lower than China. The average cost for lithium-ion battery systems ranges from $200 to $300 per kWh last decades, declined to $115 per kWh [13]. BloombergNEF's annual battery price survey finds a 14% drop from 2022 to 2023 [14]. This decline in costs has been facilitated by technological advancements and increased competition within the market. However, U.S. market does not enjoy large scale of economic of scale compare with China. In 2021, CATL, a leading Chinese battery manufacturer, had a production capacity of over 170 GWh, with plans to expand to 500 GWh by 2025 from CATL annual report [15]. In contrast, Tesla's Gigafactory 1 in Nevada had a projected capacity of 35 GWh. The larger scale of Chinese operations allows for lower per-unit costs, U.S. is in a smaller scale of operations. Moreover, the complexity of the U.S. battery supply chain significantly contributes to higher production costs, as it often involves a multi-layered network of suppliers and manufacturers that span across different countries and continents, longer time to operate and transfer, leading to increased logistical challenges and costs. The geographical dispersion of suppliers can lead to longer lead times and increased inventory costs,

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as manufacturers must maintain larger stockpiles of materials to buffer against potential supply chain disruptions.

European countries, particularly Germany, report higher costs for lithium-ion battery storage, ranging from €300 to €500 per kWh (approximately $350 to $580) [16]. These elevated costs stem from rigorous regulatory standards, a strong emphasis on sustainability, and a mature market that prioritizes safety and performance. The slower scale-up of production compared to Asia is another contributing factor to the higher pricing. The European battery market is heavily influenced by its commitment to environmental standards, often requiring more expensive materials and processes to ensure compliance with stringent regulations. Moreover, the European Union's focus on reducing carbon emissions has led to significant investments in sustainable battery technologies, which, while increasing upfront costs, may yield long-term benefits in efficiency and lifecycle management. This commitment to sustainability can create a dual-edged sword, as the initial financial burden may deter some investors, yet it positions Europe as a leader in the emerging market for green technologies

## 6. Potential Solution

Due to the general heavy pressure of energy storage system across various nations, the high cost has become a main focused problem, need to be addressed urgently. There are two methods proposed to address the problems to some degree.

### 6.1. Tax Solution

Tax incentives, particularly investment tax credits (ITC) and production tax credits (PTC), are critical financial mechanisms that significantly influence the economics of energy storage technologies by allowing consumers and businesses to deduct a substantial percentage of the installation costs from their taxable income, thereby effectively reducing the overall financial burden associated with acquiring these systems. The structure of these tax incentives is designed to stimulate market demand by making energy storage solutions more financially appealing; for instance, when a homeowner or business can reduce their taxable income through a credit that accounts for a portion of the expenses incurred during the installation of a battery system, it not only lowers the upfront cost but also enhances the return on investment by improving the overall economics of the project.

The investment tax credit has proven particularly powerful in the context of renewable energy, as evidenced by its significant impact on the solar market in the United States. According to a report by the Solar Energy Industries Association (SEIA), the ITC has driven billions of dollars in investments into solar energy and related technologies, including energy storage systems, by allowing investors to capitalize on a tax deduction that can cover up to 30% of the installation costs [17]. This has been instrumental in enabling many consumers who might otherwise be deterred by the high initial costs of solar-plus-storage systems to proceed with their investments, thereby accelerating the deployment of these technologies across the country.

Moreover, the integration of tax credits with energy storage solutions not only incentivizes individual consumers but also encourages utility companies and large-scale developers to invest in energy storage projects, as the potential for significant tax savings can enhance the financial feasibility of such initiatives. For example, California's Self-Generation Incentive Program (SGIP) exemplifies how tax incentives can drive market growth; by offering rebates based on system capacity, the SGIP has effectively encouraged thousands of installations, thereby positioning California as a leader in energy storage deployment. The SGIP illustrates that when tax credits are strategically designed to target specific technologies or market segments, they can yield substantial increases in adoption rates, which in turn fosters greater competition and innovation within the industry [18].

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However, the efficacy of tax credits and deductions still have challenges exist. The complexity of tax structures creates barriers for potential adopters who do not fully understand how to access these benefits or who might lack the necessary financial literacy to navigate the application process effectively. This complexity led to significant disparities in who benefits from available incentives, as those with more resources will better be positioned to take advantage of tax credits, which leave low-income households and less knowledgeable consumers to disadvantages. Additionally, the continuity of these incentives is often subject to the ebb and flow of political dynamics; changes in administration or shifts in public policy can lead to fluctuations in funding and support for these programs. For example, if the government decides to reduce and eliminate tax credits, it can create uncertainty in the market, prompting potential investors to delay or reconsider their decisions regarding energy storage investments. These potential risks can stymie innovation and growth, as stakeholders may hesitate to commit resources in an unstable environment.

## 6.2. Increase Supply Chain Efficiency

Reducing transportation and logistics costs in the context of battery production involves several strategic approaches that can significantly enhance competitiveness and lower overall production expenses. One key strategy is the localization of supply chains, which entails sourcing raw materials and components closer to manufacturing facilities. Companies can reduce fuel consumption, lower emissions, or decrease the time required for materials to reach production lines to minimize the total distance that materials need to be transferred. This not only cuts transportation costs but also mitigates risks associated with supply chain disruptions, such as those caused by geopolitical tensions or natural disasters. Combining with technology as helper for human to collect information and data within the supply chain operation. Use Just-In-Time inventory management technology to combine with energy storage manufacturing or operating process can increase the overall supply chain efficiency. Given the rapid advancements and fluctuating demand in the energy storage sector, particularly with the increasing adoption of renewable energy sources and electric vehicles, JIT offers a strategic advantage by minimizing the need for large inventories of costly components such as lithium, cobalt, and other critical materials, which enable more frequent updates and improvements. As companies receive materials just in time for production, they can incorporate the latest advancements and customer feedback into their products without the constraints of excess inventory [19].

Additionally, the energy storage industry can establish strategic partnerships with logistics providers that offer integrated services, such as transportation, and distribution. These partnerships can provide economies of scale and access to a broader network of transportation options, further driving down costs. As for Chinese energy industry, already adopted some ways to form partnership outside own country, to gain a better source of raw materials with lower price. However, as for U.S. tend to form or develop supply chain domestically rather than abroad, which heavily affected the overall costs and price for energy storage related areas. Moreover, leveraging multimodal transportation solutions, which combine different modes of transport such as rail, sea can offer flexibility and cost savings by selecting the most efficient routes and methods for each segment of the supply chain. Adopting sustainable practices, such as using electric or hybrid vehicles for transportation, can reduce fuel costs and align with environmental regulations, potentially qualifying companies for government incentives or subsidies.

# 7. Conclusion

As the global demand for batteries continues to rise, driven by the transition to renewable energy and electric vehicles, the energy industry has the potential to strengthen its position in the market. By addressing the key factors contributing to higher costs and leveraging its strengths in innovation, the energy storage industry can work towards achieving greater efficiency and sustainability in the battery industry. In the current global energy industry landscape, the costs of energy storage systems are trending downward. However, the primary factors driving high costs persist and continue to exert pressure. Implementing a tax system and reducing supply chain complexity could enhance efficiency and lower costs, particularly in the production of smaller components, although some challenges remain to be addressed. As countries and industries become increasingly aware of these issues, more research and case studies are being conducted. Various associations and programs are taking responsive actions in the energy sector. These developments suggest that while solutions are being sought, the future outlook is promising.

## References


*[1] Aneke, M., & Wang, M. (2016). Energy storage technologies and real life applications: A state of the art review. Applied Energy, 179, 350-377.*

*[2] Tayyib, D. M., Sekar, L., & Okoroafor, E. R. (2024). Integrated Techno-Economic and Life-Cycle Assessment of Subsurface Energy-Storage Technologies for Renewable Energy. In Abu Dhabi International Petroleum Exhibition and Conference (p. D041S141R004). SPE.*

*[3] Mongird, K., Viswanathan, V., Balducci, P., Alam, J., Fotedar, V., Koritarov, V., & Hadjerioua, B. (2020). An evaluation of energy storage cost and performance characteristics. Energies, 13(13), 3307.*

*[4] Giosuè, C., Marchese, D., Cavalletti, M., Isidori, R., Conti, M., Orcioni, S., ... & Stipa, P. (2021). An exploratory study of the policies and legislative perspectives on the end-of-life of lithium-ion batteries from the perspective of producer obligation. Sustainability, 13(20), 11154.*

*[5] Schmidt, O., Melchior, S., Hawkes, A., & Staffell, I. (2017). The future cost of electrical energy storage based on experience rates. Nature Energy, 2(8), 17110. https://doi.org/10.1038/nenergy.2017.110*

*[6] Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., ... & Anderson, P. (2019). Recycling lithium-ion batteries from electric vehicles. Nature, 575(7781), 75-86.*

*[7] Pares, F., Busch, P., Chandra, M., & Tal, G. (2023). EV Supply Modelling: Implications of Global EV Adoption Targets for Mexico’s Light-Duty Auto Industry. In Proc., 36th International Electric Vehicle Symposium and Exhibition EVS36, Sacramento, CA (pp. 1-12).*

*[8] Viswanathan, V., Mongird, K., Franks, R., Li, X., Sprenkle, V., & Baxter, R. (2022). 2022 grid energy storage technology cost and performance assessment. Energy, 2022, 1-151.*

*[9] Bouraima, M. B., Alimo, P. K., Agyeman, S., Sumo, P. D., Lartey-Young, G., Ehebrecht, D., & Qiu, Y. (2023). Africa's railway renaissance and sustainability: Current knowledge, challenges, and prospects. Journal of Transport Geography, 106, 103487.*

*[10] Lorenz, A., Peukert, L., Evans, T., & Salmon, P. (2008). Operation: Automation: The inherent benefits of automated dip-spin-tilt coating equipment when integrated with barrel plating, conversion coating and painting systems. Metal Finishing, 106(11), 14-21.*

*[11] Eggleston, L., Southall, R., Joseph, L., Jackson, A., Mekki, M., & Sorensen, G. (2024). Production and Recycling of EV Batteries: On the Road to Circularity?. Nordic Council of Ministers.*

*[12] An, H., & Cho, K. (2024). Data Analysis of Global Research Cooperation Patterns in the Secondary Battery Industry. Energies, 17(12), 3030.*

*[13] Ziegler, M. S., & Trancik, J. E. (2021). Re-examining rates of lithium-ion battery technology improvement and cost decline. Energy & Environmental Science, 14(4), 1635-1651.*

*[14] Shaikh, J., & Sharpe, B. (2023). Assessment of light-duty electric vehicle costs in Canada in the 2023 to 2040 time frame.*

*[15] Tracker, C. A. (2021). Warming projections global update. Climate Analytics and New Climate Institute: Berlin, Germany.*

*[16] Hussain, F., Arif, S. M., Aslam, M., & Ali, S. (2020). Energy storage technologies. In Energy for sustainable development (pp. 125-165). Academic Press.*

*[17] Merezhko, I. (2024). SOLAR INNOVATIONS IN THE US MARKET: HOW TO INCREASE ENERGY EFFICIENCY. Věda a perspektivy, (7 (38)).*

*[18] León-Martínez, V., Andrada-Monrós, C., Peñalvo-López, E., & Saiz-Jiménez, J. Á. (2024). Demand-Side Management Method for Households with Self-Generation and Storage of Electricity. Buildings, 14(1), 276.*

*[19] Guzmán, S. L., Fehse, M., Gucciardi, E., Cabello, M., Martin, S., Etxebarria, N., ... & Reynaud, M. (2025). Exploring separation techniques for the direct recycling of high voltage spinel LNMO scrap electrodes. Journal of Materials Chemistry A.*