The Lithium-Ion Battery (Market) Is Heating Up: Are We Ready?

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Introduction

In 2018 the U.S. Consumer Product Safety Commission released a report stating that lithium-ion batteries resulted in more than 25,000 fires or overheating issues over five years. Even with the tremendous environmental consequences, the lithium-ion battery market is set to reach over $180 billion (USD) as early as 2030, if not sooner (OSHA, 2019). The expected growth of lithium-ion batteries is because they have emerged as the primary choice for electric vehicles beyond the diverse applications in medical devices, smart watches, drones, satellites, and utility-scale storage. Lithium-ion batteries have high energy and long life (Nitta, Wu, Lee, & Yushin, 2015). As opposed to regular alkaline batteries, Lithium-Ion batteries could be used repeatedly for several years (several thousand charging cycles). But Li-Ion batteries are experiencing Environmental Supply chain and Governance (ESG) issues. This whitepaper addresses the technology required to address ESG concerns and to ensure we are prepared for the changes that will be brought about by lithium-ion battery growth resulting from the proliferation of Electric Vehicles (EVs).

Environmental Concerns

Lithium-ion batteries are used in many products, including cell phones, electronics, handheld power tools, varying-sized appliances, and electronic vehicles. Despite their small size, they have the highest energy density and the most extended lifespan for a rechargeable battery. In the short run, the growing popularity of lithium-ion batteries seems to be a positive contribution to our environment and economy as they can be considered “green” since they do not contain mercury, cadmium, or lead like other rechargeable batteries. However, this is debatable as they still contain a variety of elements that, in high quantities, could reach toxic levels if placed in a compact area.

Lithium and cobalt, the main components required to produce lithium-ion batteries, are scarce because they are only mined in a few countries, which clearly poses a threat to their availability and the sustainability of this important value chain. Lithium-ion batteries are made up of three main parts: the anode, cathode, and electrolyte, as shown in Figure 1. Critical minerals like lithium, graphite, and cobalt comprise these parts (Samsung SDI, 2016). According to the United States Geological Survey, necessary minerals are essential resources for the economic security of the United States and are vulnerable to interruption or disruption in their supply chain. In 2019, the Department of Energy published its Research Plan to Reduce, Recycle, and Recover Critical Materials in Lithium-Ion Batteries. In the report, they claimed that less than 5% of lithium-ion batteries are recycled in the United States (U.S. Geological Survey, 2022).

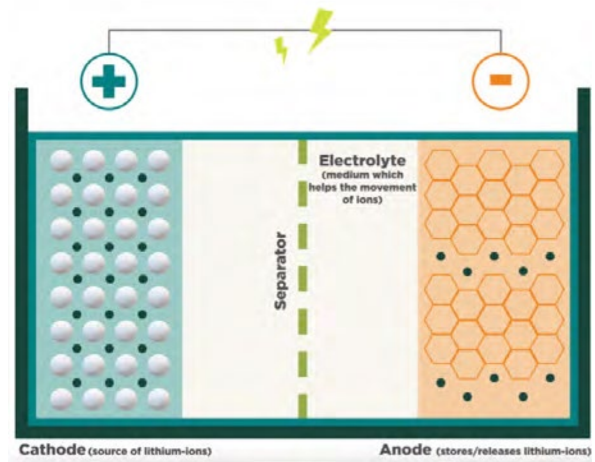

Figure 1 Battery Description

Lithium-Ion Battery Regulations: The United States vs. European Union

The lack of disposal regulations from the U.S. government is not helping this challenge. While the United States Environmental Protection Agency (EPA) does not regulate waste produced from lithium-ion batteries, it provides a best practice guide that educates users on how to dispose of and recycle them (U.S. Environmental Protection Agency, 2022). For a medium- to large-sized lithium-ion battery used in an electric vehicle, the EPA issued the following recommendation for disposal: “Contact the manufacturer, automobile dealer or company that installed the Li-ion battery for management options; do not put it in the trash or municipal recycling bins.” There are no formal federal regulations for lithium-ion battery disposal, allowing states to form their own regulations (U.S. Environmental Protection Agency, 2021). Specifically, California and New York have trailblazed the path by creating their own recycling policies for lithium-ion batteries. The only federal regulation for lithium-ion batteries is under the U.S. Department of Transportation’s (DOT) Hazardous Materials Regulations (U.S. Department of Transportation, 2022), which outlines stricter packaging, labeling, and shipping standards.

However, there are increased efforts to fund research projects and bills that were passed into law centered around sustainability in electric vehicle (EV) lithium-ion batteries as of Q4 2022 (Quinn, 2022). In October 2022, the Department of Energy (DOE) granted $2.8 billion to 20 manufacturing and processing companies across 12 states to support projects that will aid America’s independence in the EV battery supply chain. President Biden also announced the American Battery Material Initiative; its goal is to strengthen the United States’ presence in the end-to-end battery supply chain, as we currently depend on China to provide most of the critical minerals. The momentum continues as the DOE awarded $73.9 million to universities and energy companies to develop second-life battery recycling and reuse strategies (Green Car Congress, 2022).

The Biden administration also signed the Strategic EV Management Act into law at the end of 2022 (S.4057 - 117th Congress , 2022) which facilitates government agency collaboration toward a strategic plan for reusing and recycling EV batteries. The law also will develop guidelines for proper disposal of EV batteries once they can no longer be reused or recycled. Clearly, the U.S. government is invested in the future of lithium-ion batteries and is starting to take the necessary steps for a more sustainable EV battery value chain (The White House, 2022).

The European Union (EU) is taking a more direct approach in making the lithium-ion battery value chain more sustainable (Pettitt, 2022). In a legislative proposal set to be released in 2022-2023, the EU states that it currently has a 50% battery-weight recycling requirement. Starting in 2025, that requirement will increase to 65% for lithium-ion batteries (Stena Recycling, 2022). This percentage will continue to reach 70% in 2030 with additional detailed recycling requirements for minerals within the battery (lithium, cobalt, copper, nickel, and lead). The EU currently has a pending “European Green Deal,” which sets out to establish a battery passport or electronic record for electric vehicle batteries whose capacity is higher than 2kWh. A unique identifier tag must be printed or engraved on each battery.

Electric Vehicle Market and Value Chain

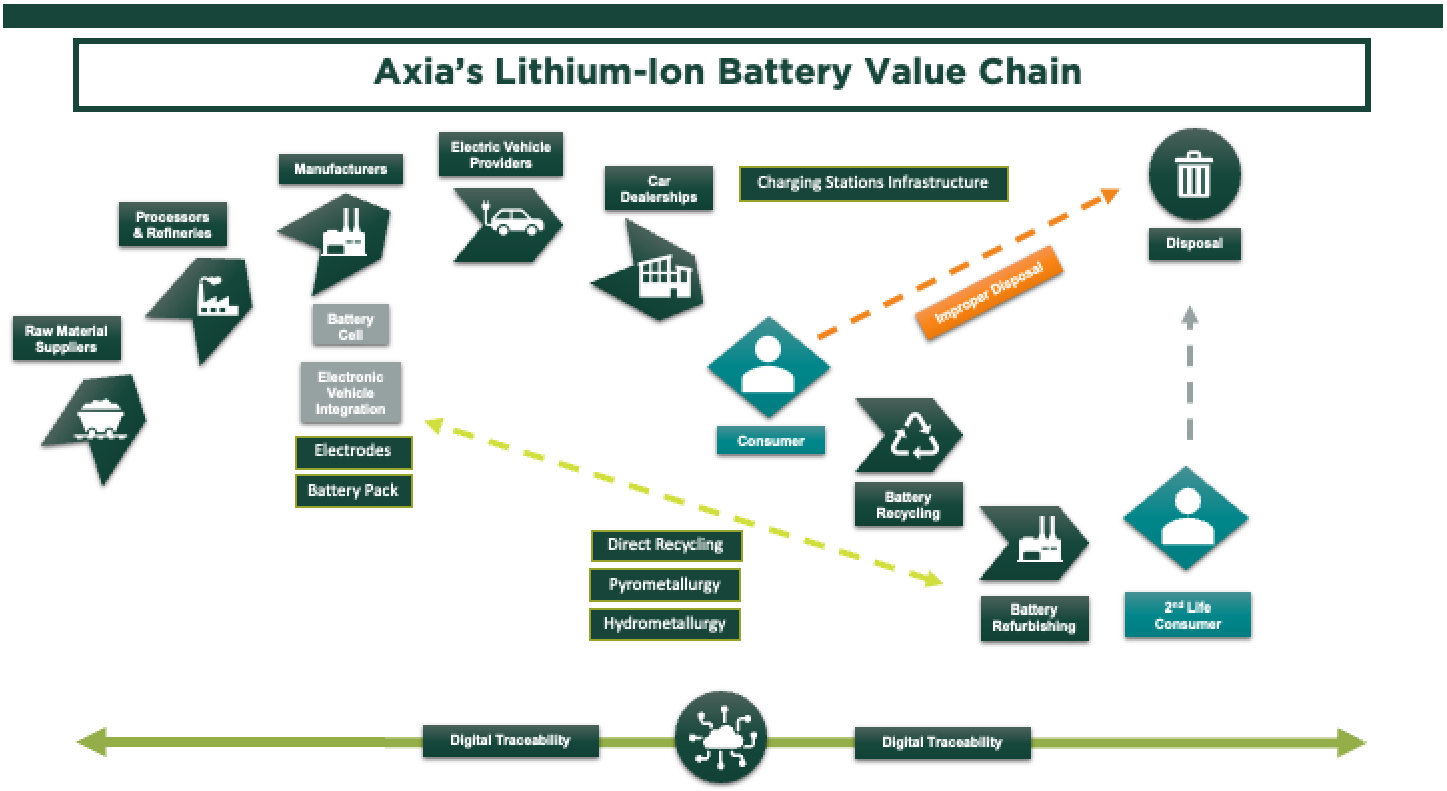

Figure 2 Axia's Lithium-Ion Battery Value Chain

Within the last decade, the electric vehicle market grew exponentially from a meager 120,000 sales worldwide in 2012 to a grand total of 16.5 million sales in 2021. Carbon-conscious mindsets have become increasingly popular among dominant automakers. In 2021, General Motors announced that by 2035 they will sell only zero-emission vehicles, and Audi revealed their goal of phasing out combustion engines by 2033. As companies steer away from burning fossil fuels, this puts a higher demand on lithium-ion batteries, which most plug-in hybrid and fully electric cars run on. The lithium-ion battery market is set to increase by 30% annually from 2022 to 2030, with a value of more than $400 billion and a market size of 4.7 TWh (Grand View Research, Inc. , 2022). The growth of the EV market is a significant contributor to this drastic increase. Benchmark Mineral Intelligence reported that in 2030, 90% of the demand for lithium will be due to the rise in the EV market.

Axia's proposed value chain ecosystem for lithium-ion batteries is split into two sections: one consisting of its first-life activities and another containing its second-life activities. The value chain starts with the raw material suppliers, primarily made up of those providing lithium, cobalt, and graphite mines. In 2021, around 80% of the world's mined lithium was from Chile, Australia, and China, as seen in Figure 3 (U.S. Geological Survey, 2022). China dominated the lithium processing and refining industry, with more than 50% market control. According to the International Energy Agency (IEA, 2022), this is due to China housing three-fourths of the lithium-ion battery mega factories in the world. Contemporary Amperax Technology Co., Ltd (CATL), a Chinese company, is the leading global manufacturer of EV batteries, with just over a third of the market (Figure 4, (SNE Research, 2022)).

The manufacturing process for the value chain occurs in two parts, one for the battery cell and one for the electric vehicle integration. The battery pack assembly varies from taking place at the battery cell or the electric vehicle integration manufacturer. From there, the lithium-ion battery is placed in an electric vehicle. The dominant market players for electric vehicles by sales are Tesla, BYD, Toyota, and General Motors.

The lithium-ion battery can go into a second life cycle. However, this is usually not the case. Seventy-five to 92% of lithium-ion batters are not discarded correctly after use, a major contributing factor to the uptick in landfill overheating issues and fires. If they are disposed of in the proper recycling centers, they can either go back into the electric vehicle lithium-ion battery value chain or be repurposed for other uses. Eventually, the battery components will degrade to a point where they are no longer salvageable and must be safely disposed of.

Describing other components in the value chain, charging stations represent a critical factor in expanding the electric vehicle's ecosystem and, therefore, batteries. Literature shows a significant correlation between electric vehicle adoption and the charging infrastructure. Thus, different government initiatives have been implemented (Marino & Marufuzzaman, 2020). For instance, the development of EV-charging infrastructure is an area of recent investment through the U.S. government's Bipartisan Infrastructure Law, which provided $7.5 billion to help support the production of 500,000 public chargers nationwide.

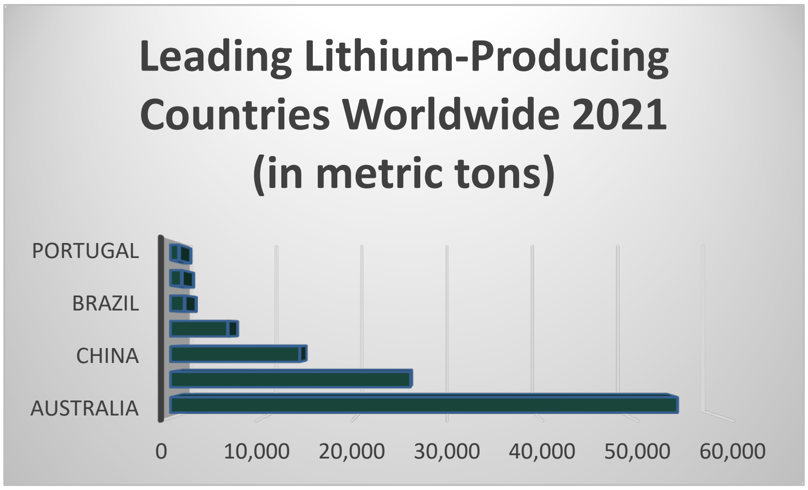

Figure 3 Lithium Producing Countries

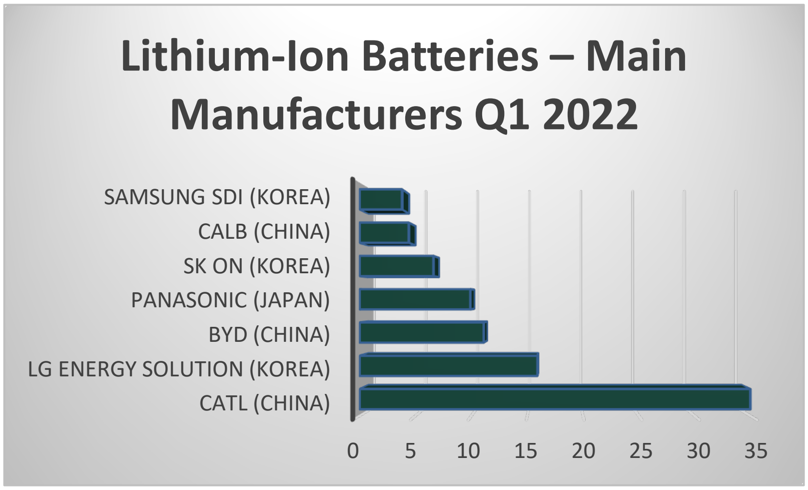

Figure 4 Lithium-Ion Batteries Manufacturers

Axia's Proposed Solution for Lithium-Ion Car Batteries and Landfill Waste Reduction

Similar to the EU's battery passport requirement, the Axia Institute views digital traceability, specifically Radio Frequency Identification (RFID), as a solution to help the development of sustainability solutions for the lithium-ion battery. Due to the immense lack of regulation, focusing on traceability for the product's afterlife is crucial in the United States. Although there may not be governmental incentives to keep track of where a company's lithium-ion batteries land, there is value in circularity and in disposing of them properly. RFID and similar traceability technologies can be read wirelessly, unlike a traditional barcode that needs to have the product's surface showing to capture identification. A wireless tag that does not require line of sight could be the solution to tracing the product due to the location of the lithium-ion battery at the end of its value chain (Baker, 2021).

RFID has already been explored and applied within the automotive industry. Major automotive manufacturers, including Volvo, Honda, and General Motors, use innovative technology for tracking and traceability purposes. An article from Automation Insights disclosed that Ultra High Frequency (UHF) RFID systems had been explored, tracking "the initial electrode coil from goods received in the warehouse, through the multiple machines in the electrode manufacturing process, into the storage areas, and to the battery cell assembly going in the electric vehicle – ultimately linking all battery cells back to a particular daughter roll, and back to its initial mother roll." The RFID tag tested could withstand temperatures up to 235 degrees Celsius with cycling applications.

Axia's proposed solution for lithium-ion battery landfill waste reduction is for automotive and lithium-ion battery manufacturers to formally integrate RFID tags into their production. Each lithium-ion battery can be tracked from the beginning of its value chain to the end use and disposal method. The RFID tag can be used internally for the electric vehicle maker or from a regulation standpoint if the United States decides to follow the EU's standards and regulations. The goal would be for the battery parts and minerals to be traced and read at different points, ensuring the value chain is in constant circulation.

HID, a leading manufacturer of secure identity products, provides RFID tags for innovative waste container management. These tags support optimizing efficiency and traceability in waste management under pay-as-you-throw and recycling incentive programs. An RFID antenna reader is placed near the lifting arm of the waste vehicle, and an RFID tag is placed on a household's waste container, tracking the weight of the waste. These programs show that the integration of RFID and waste management is indeed viable. In our proposed solution, municipalities would use an RFID system similar to the ones already established. As a household's battery waste is transferred to a waste vehicle, the RFID reader would track potentially hazardous waste, such as lithium-ion batteries. Once the waste vehicle reaches the landfill transfer station, the lithium-ion battery will be appropriately extracted and taken to a recycling center or hazardous waste area (Global, 2022).

Although there is an initial cost to implementing RFID across the lithium-ion value chain, the introduction of circularity can potentially cut costs in the primary extraction and mining of minerals. This solution provides a more sustainable option for lithium-ion battery manufacturers internally and for the lithium-ion battery market and stakeholders.

Emerging Technologies

Blockchain (a.k.a. block-chain) solutions open multiple possibilities for traceability in electric vehicle batteries. Current literature shows it as an emergent technology for batteries that are the principal component in electric vehicles (Figure 5, (Aria, M. & Cuccurullo, C. , 2017))+.

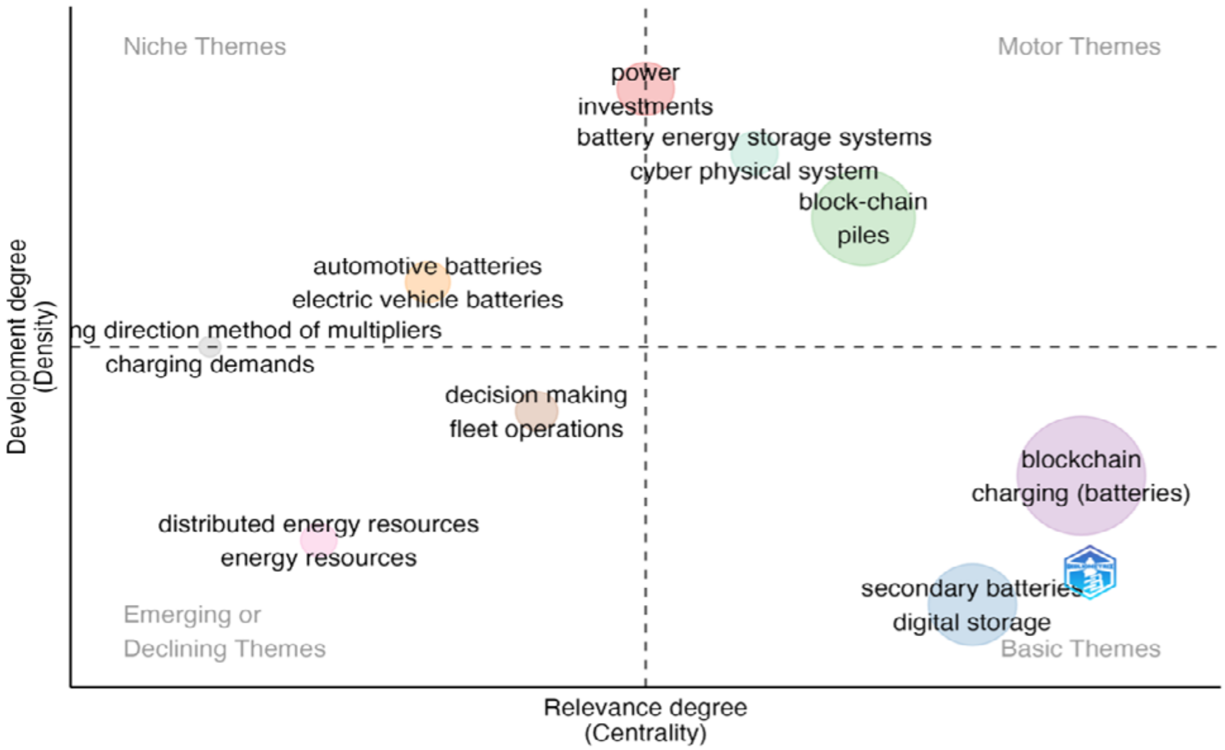

FIGURE 5 Thematic Map

State-of-the-art innovation shows the importance of the adoption of new cutting-edge technology, such as blockchain, to provide traceability in a value chain. For instance, a recent study highlights that a properly designed battery management system (BMS) is the most critical factor in the battery's safety, reliability, and optimal performance. Furthermore, it is crucial to ensure connectivity with other components in a vehicle. The study proposes adopting blockchain technology to protect BMSs from cyber-physical attacks and provide a reliable utilization of battery systems (T. Kim et al., 2022). Another study suggested a charging station energy management system based on blockchain technology to protect end-users' data privacy while meeting charging demands (Y Y. -J. Lin, et. al, 2022). In terms of traceability, a study proposed a blockchain-based battery supply chain traceability system. The study aimed to protect users' privacy, improving the system's reliability while ensuring the traceability needs of power batteries (Y. Ma and R. Fang, 2022). In short, blockchain is a promising technology to achieve full transparency across the value chain.

Li-Ion battery supply chain issues

Currently, Li-Ion batteries face several challenges in the value chain. From the upstream perspective, many raw materials have been classified as critical resources by the USA and EU not just because they need more of them, but also because even synthetic alternatives like those for graphite, as an example, are more costly. Furthermore, lithium availability itself can be considered uncertain, and it can be said that other materials used for existing batteries are found in geographically remote areas where additional concerns over unethical labor practices exist.

Other concerns in the supply chain regard environmental impacts. On one side, for manufacturing, it is necessary to use energy-intensive high-temperature annealing and solvents. Both have an enormous environmental impact. It is critical to decrease them or seek new alternatives in materials and review more disposal procedures for the by-products in the process (Shafique , M; Akbar, A; Rafiq, M; Luo, X; Shafique, M, 2023). On the other hand, from a disposal perspective, Li-Ion batteries are difficult to dismantle; thus, there are opportunities for enhancing the disassembly design or converting it towards biodegradable materials.

The United States and European Union have deployed strategies that can be considered major policy shifts because of the new legislation and the revision of current federal, national, and local policies. For the US, it blends "supply-push" (i.e., offering public funding for production and investigation of Li-ion batteries) and "demand-pull" (i.e., subsidies and tax breaks). The EU has focused on building a sustainable European battery value chain by adopting the European Battery Alliance (EBA) in 2017.

About The Axia Institute

The Axia Institute® is a premier research and education center dedicated to developing effective and sustainable solutions to improve public and private value chains. Established by Michigan State University (MSU) in 2013, the Axia Institute is part of MSU's Office of Research and Innovation and partners with industry to solve grand challenges and conduct cross-disciplinary research in areas of global logistics, pharmaceutical solutions, RFID innovations, value chain optimization, smart packaging, waste valorization, and food safety. The Institute was founded by leaders in value chain creation and development at MSU and collaborates with stakeholders at the Eli Broad College of Business, the College of Agriculture and Natural Resources, the College of Engineering, the Center for Anti-Counterfeiting and Product Protection, College of Human Medicine and the School of Packaging. Founding donors include The Dow Chemical Company, Dow Corning Corporation, The Herbert H. & Grace A. Dow Foundation, the Rollin M. Gerstacker Foundation, The Dow Chemical Company Foundation, and the Charles J. Strosacker Foundation.

Axia's approach concentrates on developing our three stakeholder consortiums: healthcare, food and agriculture, and advanced manufacturing. Please consider joining our collaboration to take on this industry challenge by expanding our research on the value chain of lithium-ion batteries. For more information, contact the Axia Institute at (989) 423-2046, or email axiainstitute@msu.edu.

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