Chloe Wilson

English 3306

Unit 1: Literature Review

APA

Research Question: *What are the environmental impacts of lithium-ion battery production?*

Purpose: *To investigate documented environmental and resource impacts of lithium-ion battery production considering applications in electric vehicles, and to explore the efficacy of methods reducing adverse effects.*

Literature Review of Environmental Impacts of Lithium-Ion Batteries (LIBs)

Lithium-ion batteries, or LIBs, have revolutionized electronics and energy storage with their higher energy density and environmental advantages. As industries respond to climate change, demand for effective energy storage mechanisms has grown exponentially for a wide range of applications in electronics, supplements to a hybrid grid, and decarbonized motor transport. Lithium-ion batteries are commonly employed in electric vehicles, a market anticipating demands to increase twenty-eight times by 2050 compared to 2016 (Kosai et al., 2021, Turcheniuk et al. 2018). However, all LIBs consist of various metals that require intensive mining operations to extract, and may involve refinement processes that pose potential health risks to employees. As demand for LIBs increases across market sectors, it is crucial to consider the life cycle impacts of their production through an environmental lens. A literature review was conducted to better analyze the range of environmental impacts involved in the extraction of raw resources for a lithium-ion battery and the potential of recycling methods on the sustainability of lithium-ion battery production.

A wide range of sources were reviewed to better understand the holistic impact of resource extraction and processing into LIBs. As research into lithium-ion battery composites and their related life cycle analyses are ongoing, sources from before 2017 were not considered for this review. This literature review does not explore ongoing research into new cathode compositions, and the studies examined are only valid for existing cathodes for which ample research has been conducted. Journal articles were found using Google Scholar and by exploring the overall LIB life cycle analyses, the environmental impacts of their key composite metals such as cobalt and lithium, the ethics involved in related mining operations, and considering environmental impacts of LIBs in the context of their application in electric vehicles. Other sources were found through similar google searches and published online media.

As a composite product, there are a number of raw resources required to produce a functioning lithium-ion battery. An LIB cell consists of an anode, a cathode, an electrolyte, a separator, and a cell container (Kosai et al., 2021). Out of these, the anode and cathode consist of metals like graphite, cobalt, nickel, manganese, and other elements, which can vary depending upon the cathode composition. Several studies report on the difficulty of creating a holistic life cycle analysis for LIBs due to the wide range of cathode compositions in use (Kosai et al., 2021; Sadhukhan et al., 2021). Various cathodes may have certain metals in greater quantity, or different metals entirely, whose methods of extraction and base resource availability greatly impact the resulting environmental impact, land use, and resource management required to extract and process them. Studies into common LIBs and studies which explored several cathodes were selected with this internal variability in mind.

A major concern with the production of an LIB is the associated land disturbances. In a life-cycle analysis study conducted by Shoki, the total material requirement by mass for the production of an LIB was explored. This analysis included both direct and indirect resource inputs as well as indirect or hidden flows of mine waste. This study concluded that the production of a single lithium-ion battery disturbs land mass and natural resources 200 times heavier than the battery itself (Kosai et al., 2021). These land disturbances often occur during the mining and extraction of metal and raw resources. A key concern explored in several studies are mine tailings. Mine tailings are a slurry of unwanted materials left behind in a mining operation after the target mineral has been extracted (Wang et al., 2019; Kosai et al., 2021). Many of the materials in these tailings are heavy metals and minerals resources that had been brought to the surface during the mining operation. If these tailings are not properly addressed, as occurs in dozens of countries, the heavy metals leftover in the tailings can contaminate agricultural soils, surface water, groundwater, sediments, plants. As a consequence, nearby residents who may accidentally ingest this contaminated food and water may suffer great health risk (Wang et al., 2019). In order to meet the projected growth of the LIB market, land resource studies suggest that nearly 80 large-scale tailing dams would be constructed, which have a greater risk of disastrous collapse (Kosai et al., 2021). The dangers of abandoned and ill-managed tailings upon local biodiversity and residents are well understood and pose a prominent environmental risk.

In the context of an ever-growing climate crisis, several studies touched upon the greenhouse gas emissions, or GHG emissions, involved in the life cycle of a lithium ion battery. A recent life-cycle analysis study determined that 6.7 kg of CO_2 are generated per kg of lithium-ion battery when accounting for carbon dioxide contribution of recycled materials through associated supply chains (Sadhukhan et al., 2021). Another study exploring the GHG emissions of various LIB types determined that cell production generates around 9 $kgCO_2eq$

averaged across all considered types (Ciez et al., 2019). With electric vehicle batteries weighing upwards of 600 kg and electric vehicle production projected to increase rapidly in coming decades, this contribution to greenhouse gases should be considered, but studies do not consider it to be a major environmental concern compared to other factors such as land disturbances (Turcheniuk et al., 2018). This impact was quantified in a different study, which considered greenhouse gas emissions involved in battery life cycle in the context of its energy storage. It was determined that in order to produce 1 Wh or storage capacity in a lithium ion battery, the required energy demand for material production was 328 Wh and was associated with greenhouse gas emissions around 110 gCO_2eq (Peters et al., 2017). This energy inequality reflects the drive behind ongoing research into battery optimization and other battery types which have a greater energy density. It should be noted, however, that the CO_2 emissions involved in lithium battery production are relatively small in the context of their applications, such as in electric vehicles.

A major resource concern for the projected demand of lithium-ion batteries is the shortage of heavy minerals like cobalt, manganese, copper, and nickel. A 2018 article in *Nature* urged for research into alternative battery cathodes, citing the dwindling material resources of cobalt and nickel. It was estimated that demand for cobalt will exceed available resources by 2030, and similarly that demand for nickel will exceed resources by 3037 (Turcheniuk et al., 2018). The article urges alternative metals which are more abundant, such as iron and copper, to be incorporated into future cathodes. However, it should be noted that the life cycle analysis by mass conducted by Kosai et al. determined that the copper ore grades used in current LIBs had the greatest effect upon the total land use by mass required for LIB production (Kosai et al., 2021). As high-grade copper ore deposits are rapidly exploited, lower copper grades that require even greater land disturbances will be overexploited. As the global market uses more low-grade copper deposits, Kosai et al. anticipate an exponential rise in the land disturbances involved in lithium ion battery production (Kosai et al., 2021). These studies indicate that mineral resources required to produce LIBs are not abundant enough to meet projected demand, and that existing alternatives would still generate increasingly negative environmental impacts as ore deposits dwindle.

In light of the resource scarcity of fundamental materials in LIB production in combination with associated land disturbances, much research has been conducted on the potential sustainability of lithium-ion batteries through recycling practices. Successful recycling practices can extract minerals like cobalt, nickel, and manganese for reuse in other products. Depending on the type of LIB cell, recycling practices can offset GHG emissions by 2 $kgCO_2eq$, but only 22% of the studied cell types reduced CO_2 emissions via recycling processes (Ciez et al., 2019). This study indicates that although GHG emission reduction is possible through recycling, it is only viable for specific cases. A study conducted by Golroudbary et al. determined that recovering lithium from spent LIBs would not be sustainable with current technology, as it requires 38-45% more energy use and 16-20% higher greenhouse gas emissions than the initial production of the battery (Golroudbary et al., 2019). Decarbonizing the electric grid and improved carbon capture technology may assist in decreasing these adverse effects in the future. The pyrometallurgical and hydrometallurgical processes used to recycle battery components can have intensive energy and water requirements, and offer minimal environmental benefit (Ciez et al., 2019). From an economical perspective, Ciez et al. determined that only certain cathode types with high cobalt and nickel content would be profitable to recycle. In the context of mineral shortages, the 2018 *Nature* article warns that if demands for electric vehicles reach expected heights, upwards of 50 to 80 million per year, then current recycling practices for LIBs would not be enough to replenish supplies (Turcheniuk et al., 2018). The general consensus of these studies is that the benefits of existing recycling practices are tangible, but often minimal in the context of battery life cycle.

Overall, a wide range of studies have explored the environmental impacts of lithium-ion battery production. Analyses of land disturbances across battery life cycle raise concerns over mine tailings and heavy metal contamination. Research into the greenhouse gas emissions of LIBs indicates a tangible contribution that should be considered in future research surrounding effects of LIBs upon climate. While much research has been conducted into the viability of recycling practices, various studies exploring the economic and environmental benefits generally agree that the benefits are minimal in context. Ongoing research into alternative battery types which are less dependent upon costly heavy metals should be explored in future reviews to identify possible improvements in these areas.

Bibliography:

Ciez, R. E., & Whitacre, J. F. (2019, February 11). *Examining different recycling processes for lithium-ion batteries*. Nature News. Retrieved February 4, 2022, from https://www.nature.com/articles/s41893-019-0222-5

Golroudbary, S. R., Calisaya-Azpilcueta, D., & Kraslawski, A. (2019). The life cycle of energy consumption and greenhouse gas emissions from Critical Minerals Recycling: Case of lithium-ion batteries. *Procedia CIRP*, *80*, 316–321. https://doi.org/10.1016/j.procir.2019.01.003

Kosai, S., Takata, U., & Yamasue, E. (2021). Natural resource use of a traction lithium-ion battery production based on land disturbances through mining activities. *Journal of Cleaner Production*, *280*, 124871. https://doi.org/10.1016/j.jclepro.2020.124871

Peters, J. F., Baumann, M., Zimmermann, B., Braun, J., & Weil, M. (2017). The environmental impact of Li-ion batteries and the role of key parameters – a review. *Renewable and Sustainable Energy Reviews*, *67*, 491–506. https://doi.org/10.1016/j.rser.2016.08.039

Sadhukhan, J., & Christensen, M. (2021). An in-depth life cycle assessment (LCA) of lithium-ion battery for climate impact mitigation strategies. *Energies*, *14*(17), 5555. https://doi.org/10.3390/en14175555

Turcheniuk, K., Bondarev, D., Singhal, V., & Yushin, G. (2018, July 25). *Ten years left to redesign lithium-ion batteries*. Nature News. Retrieved February 4, 2022, from https://www.nature.com/articles/d41586-018-05752-3

Wang, P., Sun, Z., Hu, Y., & Cheng, H. (2019). Leaching of heavy metals from abandoned mine tailings brought by precipitation and the Associated Environmental Impact. *Science of The Total Environment*, *695*, 133893. https://doi.org/10.1016/j.scitotenv.2019.133893