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Industrial Ecology and the Just Transition:
Lithium extraction, manufacturing, and end-of-life management for electric vehicle batteries

By

MARGARET STEWART SLATTERY
DISSERTATION

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Abstract

This dissertation examines clean energy supply chains in the context of the just transition and circular economy frameworks, focusing on a central technology for zero-emissions transportation: lithium-ion batteries (LIBs) for electric vehicles (EVs). I focus on three phases of the LIB life cycle: mineral extraction, component and cell manufacturing, and end-of-life management. In Chapter 1, I analyze an ongoing lithium development in Southeast California ("Lithium Valley") through the lenses of distributive, procedural, recognition, and restorative justice. Chapter 2 quantifies the environmental impacts of producing battery cells in a manufacturing hub powered by geothermal energy. I use life cycle assessment to estimate greenhouse gas emissions and other environmental impacts compared to other production scenarios and calculate the anticipated water use, energy demand, and waste generation in the context of local resource constraints. Finally, in Chapter 3, I explore the network of stakeholders that handle retired EV batteries in North America. Using semi-structured interviews, I chart out the current market-based system, discuss how stakeholders expect their sectors to evolve in the future, and identify how policymakers can support domestic reuse and recycling. Taken together, I hope this work will provide a holistic snapshot of the rapidly evolving battery landscape, while contributing actionable ideas about how we can build a climate-stabilized future where communities are protected, and materials are reused and recycled responsibly.

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Introduction

Background and Motivation

Industrialized societies are at a pivotal moment in history. In their most recent report, the Intergovernmental Panel on Climate Change reported with high confidence that human-caused climate change is already affecting climate extremes in every region across the globe, leading to "widespread adverse impacts and related losses and damages to nature and people" (IPCC, 2023). At the same time, we are also making notable, if slow and conflict-ridden, progress toward decarbonizing our energy and transportation systems. For example, in 2023, low-carbon resources supplied 54% of California's in-state electricity generation (U.S. EIA, 2023).

Progress towards decarbonization has largely been enabled by advancements in renewable energy technology, such as wind and solar power, and battery-powered electric vehicles (EVs). While they reduce greenhouse gas (GHG) emissions, producing these technologies still requires mining and other industrial processes that present distinct environmental burdens in the communities where they are produced. Developing climate strategies that are sustainable and equitable from a life cycle perspective requires examining these emerging clean energy supply chains, including how they are developed, who is impacted, and what happens when clean technologies reach the end of their useful life. With that goal in mind, this dissertation analyzes a technology that is central to the clean energy transition: lithium-ion batteries (LIBs).

Lithium-ion batteries. LIBs play a key role in global efforts to combat climate change. In the transportation sector, their energy density has allowed electric vehicles (EVs) to achieve a driving range that can compete with fossil fuel-powered cars (Fletcher, 2013). These "Zero Emissions Vehicles" are a cornerstone of most strategies to reduce carbon dioxide emissions, including California's (CARB, 2021). Batteries are also used to mitigate the intermittency of renewable energy sources, e.g., by storing electricity from solar panels then discharging it when the sun goes down. The price of LIBs decreased from over $1,000/kWh in 2010 to roughly $200/kWh in 2018, speeding adoption in transportation and storage (Goldie-Scot, 2019).

LIBs rely on lithium, of course, but also cobalt, nickel, graphite, manganese, iron phosphate, and copper (depending on the cathode composition). Likewise, solar photovoltaic panels require materials such as silicon, aluminum, and silver, and wind turbines use permanent magnets with rare earth elements (International Energy Agency, 2021). Altogether, the International Energy Agency (IEA) estimates that achieving net-zero emissions by 2050 would require six times the mineral inputs for manufacturing compared to today.[1] Lithium demand is projected to grow over 40 fold by 2040 (ibid.).

Like nearly every other projection of lithium demand, the IEA's estimate assumes that passenger cars will be the dominant form of travel in the future, with vehicle sales rising alongside economic growth across the globe (Henderson, 2020). Estimated lithium demand is lower under

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[1] Here, it's worth mentioning that these numbers refer to manufacturing only. Renewable energy and electric vehicles avoid the need to continue consuming material (e.g., petroleum or coal) for fuel and significantly reduce the overall need for extraction (Krane & Idel, 2021).

transportation scenarios that favor public transit, active mobility, smaller vehicles, and high recycling rates (Riofrancos et al., 2023). However, even under the most optimistic assumptions regarding collection and material recovery rates, the projected volume of retired batteries is only 38-60% of the estimated total demand for lithium in 2040 (Riofrancos et al., 2023; J. Dunn et al., 2021). As such, new lithium extraction sites and technologies will inevitably be needed to achieve zero-emissions transportation, at least in the short term.

Just transition and energy justice. Greenhouse gas emissions are not the only issue associated with fossil fuel-based energy and transportation, though they are perhaps the most existential. The extraction and combustion of fossil fuels also cause local environmental damage that disproportionately burdens communities of color, impoverished communities, and Indigenous people across the globe. Oil spills and environmental damage from fossil fuel extraction have devastated ecosystems and the communities they support, from the Niger Delta to the Isle de Jean Charles in Louisiana (Maldonado, 2018; Ordinioha & Brisibe, 2013; Ratcliffe, 2019). Meanwhile, coal-burning power plants emit toxic pollutants that disproportionately burden African American communities in the United States (Lowery et al., 2002). The pervasive intersection of racism, injustice, and disproportionate exposure to environmental hazards (which is by no means limited to fossil fuels) led to the creation of the environmental justice (EJ) movement and paradigm in the 1980s and 1990s (Agyeman et al., 2016; Taylor, 2000).

Activists and scholars in EJ have called for climate strategies that promote equity and repair, rather than exacerbate, economic inequality and environmental injustice (Baker, 2018; Schlosberg & Collins, 2014; ITUC, 2016). This concept is often discussed in the framework of a “just transition” to a low-carbon economy (McCauley & Heffron, 2018; Newell & Mulvaney, 2013). Traditionally, the just transition approach addressed the need to support fossil fuel industry workers who were likely to lose their jobs by centering clean energy jobs in climate discourse (Abraham, 2017), but has since expanded to encompass prioritizing communities who lack energy access or have been harmed by the fossil fuel-based energy system. A closely related concept is Energy Justice (Baker et al., 2019; Elmallah et al., 2022; Jenkins et al., 2016). As defined by Baker et al. (2019), “Energy justice refers to the goal of achieving equity in both the social and economic participation in the energy system, while also remediating social, economic, and health burdens on marginalized communities” (pg. 9). Here, I apply this concept to clean energy supply chains.

Supply chains and the just transition. Viewed through the lens of energy justice, the sudden increase in demand for clean energy minerals presents both opportunity and threat. The increase in material demand, coupled with heightened consumer awareness about sustainability, may present an opportunity to change destructive and inequitable practices that have characterized the mining industry in the past and uplift communities in mineral-producing regions (Sovacool, Ali et al., 2020). This could be particularly true for lithium because decarbonization policy has greater potential to influence supply chain practices. While there are many end-use applications for other LIB materials like nickel and copper, LIBs could drive up to 90% of the demand for lithium by 2040 (International Energy Agency, 2021). Additionally, reducing dependency on combustible fuels presents an opportunity to move away from a linear economy-- where products are made, used, and thrown away-- to a circular one, where products are reused, and materials are recycled and recovered.

At the same time, without a deliberate effort to incorporate the principles of energy justice throughout the life cycle of clean technologies, the clean energy transition risks perpetuating unequal patterns of development and injustice on a global scale (Baker, 2018; Kramarz et al., 2021). The existing LIB supply chain echoes historic patterns of colonialism and global inequality, where raw minerals are largely extracted in the Global South, then exported for value-added processing and manufacturing. Most EVs are consumed by wealthier drivers in industrialized countries, meaning these communities experience the associated environmental benefits of reduced air pollution. At end-of-life, batteries from consumer electronics are exported to less industrialized countries and managed in informal waste sectors, creating a public health hazard for the workers and communities near sites of disposal (Amankwaa et al., 2017). The disparity between who experiences benefits, such as improved air quality, and who experiences the environmental burdens from production and disposal, has been referred to as the "decarbonization divide" (Sovacool et al., 2020).

Increasingly, social scientists use the term "green extractivism" to describe the observation that clean energy supply chains are perpetuating, rather than replacing, unequal patterns of development between resource-producing countries in the Global South and consuming countries in the Global North (Kingsbury, 2021; Mejia-Muñoz & Babidge, 2023). Scholars researching green extractivism present clean energy mineral supply chains as late-stage capitalism's strategy to rise from the ashes of a planet it has systematically destroyed, with the same institutions rebranding themselves as "sustainable" to extract a different set of resources as they attempt to cling to power (Voskoboynik & Andreucci, 2022). Jerez et al. (2021) refer to this phenomenon as "the colonial shadow of green electromobility." Kramarz et al. (2021) analyze the supply chains for wind turbines, solar photovoltaic panels, and LIBs using a “typology of displacement” that includes the dispossession of local populations from their land and livelihoods, ecological degradation, and systemic unequal exchange that reinforces dependency and underdevelopment. They conclude that improved transnational governance and protective mechanisms are necessary to support an equitable clean energy transition; otherwise, the success of the transition will be “continuously threatened by the populations it leaves behind” (pg. 2).

Research Approach

Alignment with the just transition framework requires a closer investigation of how clean energy supply chains are developed, who is impacted, and what happens when technologies reach the end of their useful life. In this dissertation, I explore these questions using a mixed-methods approach that combines industrial ecology with qualitative research methods.

Industrial ecology. Robert White (1994) defined industrial ecology as “the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources”. The origin story of industrial ecology is commonly traced to a group of progressive intellectuals in Belgium, who noted that the sectoral unlinking of the Belgian economy was resulting in three forms of dysfunction: the generation of residues that were managed as wastes instead of resources, excessive energy expenditures, and systemic pollution that degraded the environment (Billen et al., 1983). The field has since evolved and expanded, but the overarching goal remains the same: “to avoid narrow, partial analyses that can overlook important variables and, more importantly, lead to unintended consequences” (Lifset & Graedel, 2002).

Two of the most prominent tools in industrial ecology are life cycle assessment (LCA) and material flow analysis (MFA). LCA identifies the inputs and outputs involved in the processes that comprise a product's life cycle and calculates their environmental impact across various categories (ISO, 2006; Tillman & Baumann, 2004). LCA is widely used by policymakers and influential institutions, including the International Energy Agency and Intergovernmental Panel on Climate Change, typically to compare the GHG emissions associated with different technologies and pathways (e.g., IEA, 2021, 2022; Krey et al., 2014). In the context of LIBs, researchers have used LCA to compare the environmental performance of EVs with internal combustion engine (ICE) vehicles (Cooney et al., 2013; Hawkins et al., 2013), understand the impact of producing batteries and battery materials (Ambrose & Kendall, 2019; Dai et al., 2019; J. B. Dunn et al., 2012; Kelly et al., 2019, 2021; Wu et al., 2021), and evaluate the environmental benefits of reuse and recycling (Bobba et al., 2018; Ciez & Whitacre, 2019; Dunn et al., 2023; Kim et al., 2019; Yang et al., 2020).

Meanwhile, MFA maps out the stocks and flows of a product or specific material within a defined spatial and temporal boundary (Brunner et al., 2003). Researchers use MFA to forecast the volume of materials required to support EV deployment and the ensuing waste stream (Liu et al., 2021; Shafique et al., 2022; Song et al., 2019). MFA can also be used to analyze potential circularity, i.e., the ability of recovered materials to meet the demand for new batteries. For instance, our research group used MFA to calculate future flows of critical battery minerals and the potential for retired batteries to meet material demand based on assumptions about battery composition, regional EV sales, and estimated lifespans (Dunn et al., 2021).

The studies above have contributed crucial information to our understanding of LIB supply chains and sustainability. At the same time, industrial ecology, as it has traditionally been practiced, has shortcomings that must be addressed to evaluate climate strategies within a just transition framework. Critiques of industrial ecology primarily stem from the field's reliance on quantitative methods and generalized results, which conceal key spatial, temporal, and human aspects of sustainability (Breetz, 2017; Mulvaney, 2014; Reap et al., 2008). Industrial ecology scholars have acknowledged that the environmental and technological systems they study "do not exist in a vacuum" and that industrial ecologists "should be familiar not just with the techniques and principles of the field, but also the cultural and legal context within which they are embedded" (Allenby, 2002). Furthermore, evaluating EJ in the LIB commodity chain requires expanding the scope of analyses beyond GHG emissions to include local impacts (Agusdinata et al., 2018; Heffron, 2020; Kramarz et al., 2021; Rossi et al., 2021; Sovacool, Hook, et al., 2020). This has been a persistent challenge in LCA due to the lack of data about toxicity, land use, and water consumption, and the complexity of modeling unique local environments (Finnveden, 2000; Reap et al., 2008). One of the principal contributions of this dissertation is incorporating qualitative methods to achieve a more holistic analysis of the LIB life cycle.

Mixed-methods research. Qualitative research can provide important context to LCA and MFA studies by shedding light on impacted populations and decision-making processes and connecting abstract, generalizable results to place- and sector-specific realities. Vice versa, LCA and MFA offer quantitative insights that can help ground social science research. For example, critiques of lithium extraction often recommend recycling as an alternative source of material supply (e.g., Blair et al., 2023; Dominish et al., 2019). LCA and MFA provide a quantitative basis for these recommendations; for example, by estimating how much material can realistically be sourced from recycling and providing context about the impacts of clean energy minerals compared to fossil fuel extraction.

In this dissertation, I use qualitative methods to incorporate the perspectives of stakeholders outside academia. This captures a more nuanced and accurate representation of the lithium-ion battery industry and connects my research with communities directly impacted by the clean energy transition. In doing so, I aim to avoid “undone science,” a term used by scholars in the field of science and technology studies (STS) to describe “areas of research identified by social movements and other civil society organizations as having potentially broad social benefit that are left unfunded, incomplete, or generally ignored” (Frickel et al., 2010, p. 445). Undone science is attributed to historical patterns of funding that reflect institutional priorities (for example, of government or private industry) rather than those of local communities, which results in systemic knowledge gaps surrounding the local and public health impacts of industrial developments (Hess, 2009; Ottinger, 2013). Correcting undone science requires deliberately investigating impacts that are relevant to local communities and learning from their lived experience (Lowe, 2021; Ottinger & Cohen, 2012).

Chapter Organization

Each chapter in this dissertation is a standalone article that investigates a distinct aspect of the LIB supply chain. The first chapter, “Energy Justice in Critical Mineral Supply Chains: The Case of Lithium Valley,” analyzes an ongoing lithium development in Southeast California (“Lithium Valley)” through the lenses of distributive, procedural, recognition, and restorative justice. The analysis is guided by content analysis of public meeting transcripts and community meeting observation to identify topics and themes that are high priorities for communities impacted by the development, which I connect with a review of technical literature and policies about geothermal and lithium extraction and contextualize in the region's history and social and environmental context. I identify positive actions to support EJ that could serve as examples in other developments, as well as challenges and recommendations. Chapter 1 makes a valuable contribution to quantitative sustainability research by elevating the priorities of local community members, whose perspectives are often overlooked in science, and connecting environmental and socioeconomic impacts with more complex layers of history and social context.

Chapter 2, "The Global Benefits and Local Impacts of Producing Lithium-ion Batteries in a Geothermal Manufacturing Hub," further explores the Lithium Valley development, where the ultimate vision is to build a battery manufacturing hub that uses lithium locally, rather than exporting it for value-added processing. I use LCA to estimate the emissions of such a hub compared to other manufacturing pathways and estimate the anticipated water and waste impacts considering the regional context. This chapter makes several novel contributions to academic literature about LIBs. First, it quantifies the benefits of collocating manufacturing near a mineral resource, which has not been investigated to date, and delineates the relative benefits of different production choices on overall sustainability (e.g., using low-carbon inputs for process energy instead of fossil fuels and reducing shipping distances). The LCA also improves upon existing estimates of the environmental of impact DLE by incorporating a pretreatment process based on publicly available patents. Finally, including a complementary analysis of high-priority local impacts in context (i.e., waste and water) responds to critiques about the lack of place-specific analyses in industrial ecology.

Finally, Chapter 3 is a network analysis of stakeholders involved in the end-of-life vehicle and LIB processing and management. This research is based on semi-structured interviews with auto dismantlers, dealership personnel, manufacturers, parts suppliers, battery aggregators, battery repurposers, and battery and scrap metal recyclers. The contribution of this chapter is to transparently map out the flows of vehicles, batteries, and constituent materials, which will enable researchers to model LIB retirement pathways more accurately and provide informed policy recommendations.

Together, the chapters present a holistic snapshot of the rapidly evolving battery landscape while contributing actionable ideas to build a climate-stabilized future where communities are protected and materials are reused and recycled responsibly.

Chapter 1: Energy Justice in Critical Mineral Supply Chains: The Case of "Lithium Valley," California

This chapter contains text originally published in the following article and report:

1. **Content analysis methodology and results**: Slattery, Margaret, Alissa Kendall, Nadiyah Helal, and Michael L. Whittaker. 2023. "What Do Frontline Communities Want to Know about Lithium Extraction? Identifying Research Areas to Support Environmental Justice in Lithium Valley, California." *Energy Research & Social Science 99 (May): 103043.*
2. **Background on Lithium Valley:** Dobson, P., et al. 2023. "Characterizing the Geothermal Lithium Resource at the Salton Sea." Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA (United States). https://doi.org/10.2172/2222403.

Abstract:

This chapter examines early-stage lithium development in California through the lenses of distributive, procedural, recognition, and restorative justice. Content analysis of public meeting transcripts indicates that water availability, employment, public health, and infrastructure are high priorities for stakeholders in the development; however, participants in community-focused meetings mainly asked about the potential impact of the development, while state-led meetings more often discussed the benefits, such as job creation or sustainability compared to other forms of lithium extraction. These priorities are highly informed by the regional context, specifically the history of environmental degradation and marginalization, compounded by drought and water scarcity. For researchers studying sustainability in quantitative disciplines, this highlights the importance of addressing local environmental impacts and considering place-specific factors, including existing social disparities.

Several positive initiatives undertaken in Lithium Valley could be applied to other developments, including a lithium tax that is directed to frontline communities and environmental restoration, workforce development programs to train residents for jobs; and a programmatic environmental impact review with funding to support outreach by community-based organizations. Nonetheless, this analysis highlights two fundamental challenges that may come to define environmental justice for clean energy supply chains: the tension of balancing the urgency of climate change mitigation with the time required for meaningful participation, and the difficulty of providing information about novel and proprietary technologies. To navigate these tensions, I recommend that policymakers and industry proactively establish plans to monitor environmental impacts and engage in facilitated dialogue with communities to understand their concerns and perspectives, with sufficient time for these engagements to shape the development. Researchers can also play a key role by partnering with community-based organizations, studying local environmental and public health impacts, and evaluating social and economic impacts such as employment, infrastructure investment, and cost of living.

Introduction

Most climate change mitigation strategies depend on replacing fossil fuel-powered electricity with electricity from renewable sources and replacing internal combustion engine (ICE) vehicles with electric vehicles (EVs) (CARB, 2021; Gill et al., 2021). While these strategies reduce dependence on fossil fuels, they rely on a different suite of resources known as "clean energy minerals" (International Energy Agency, 2021). For example, demand for lithium, cobalt, nickel, and graphite will increase significantly due to the central role of lithium-ion batteries (LIBs) for EVs and stationary energy storage (International Energy Agency, 2021). This chapter focuses on lithium, the only non-substitutable element in LIBs. To supply the technologies needed to keep global warming under 2° C, the World Bank estimates that lithium production will need to increase to nearly 500% of current production levels by 2050 (Hund et al., 2020). As the United States (US) and other regions look to reduce their vulnerability to critical mineral supply chain disruptions, there has been a government-led push to identify new domestic lithium resources (Riofrancos, 2022).

Southeastern California is home to one such resource that has garnered widespread attention: "Lithium Valley" (Paz et al., 2022). Lithium Valley refers to an area in Imperial Valley, which is East of San Diego near the United States-Mexico Border. Here, lithium resources are contained in geothermal brine from the Salton Sea Geothermal Field. Several companies are attempting to recover lithium from the brine using direct lithium extraction (DLE), a method of separating lithium from brine through chemical processing, rather than relying on the more common, slower process of natural evaporation (Stringfellow & Dobson, 2021). The deposit is considered one of the most promising sources of lithium brine in the United States (US) (McKibben et al., 2021; Toba et al., 2021; Warren, 2021), and there has been strong support for Lithium Valley at a State and Federal level (California Energy Commission, n.d.; Department of Energy, n.d.; National Renewable Energy Lab, 2021).

A broad coalition of stakeholders is working to develop the lithium resource in a way that will uplift the surrounding communities while minimizing environmental harm (Paz et al., 2022). DLE has a smaller physical and water footprint than status quo lithium production methods and can use energy from onsite geothermal power plants, resulting in lower carbon emissions (McKibben et al., 2021; Huang et al., 2021). However, DLE is an emerging technology, and most information about the process and its impact comes from the industry rather than peer-reviewed literature or other independent sources. Furthermore, industrial developments and mineral extraction have a global legacy of failed promises to benefit local communities (Ross, 1999), and the Salton Sea region has experienced a unique legacy of environmental burden and marginalization (Johnston et al., 2019; London et al., 2018; Voyles, 2021). The proactive attention to inclusive development in Lithium Valley presents an opportunity to avoid repeating past mistakes, but this is not a given. Aligning the development process with energy justice principles will be critical for achieving a just outcome.

Energy justice is often discussed in terms of David Schlosberg's "trivalent justice," which encompasses distributive justice, procedural justice, and recognition justice (Dutta et al., 2023; Schlosberg, 2007). Distributive justice questions how the benefits and burdens of a system, development, or technology are distributed; recognition justice acknowledges which communities are involved and their relationship to the place or resource, including groups that have historically been excluded from the political process and their ways of knowing the environment; and procedural justice questions whether all impacted groups can meaningfully participate and shape the outcome of decision-making processes. The three are interdependent; for example, aligning public participation processes with the principles of procedural justice helps achieve more distributively just outcomes because communities are empowered to advocate for their needs (Schlosberg, 2007). Conversely, there are many examples of communities of color and impoverished communities that are exposed to disproportionate environmental burdens and inequitable levels of risk due to their lack of recognition and political power (Agyeman et al., 2016).

A fourth dimension of environmental justice that is highly relevant to clean energy supply chains is restorative justice, which addresses the need to repair harm and remedy past injustices (Forsyth et al., 2021; Golub et al., 2013; McCauley & Heffron, 2018). Golub et al. (2013) contend that attention to the injustices suffered by past generations is necessary to understand the present and promote sustainability. They provide several examples of how the past influences present situations of injustice, which are highly relevant to clean energy mineral extraction. These examples include Indigenous lands stolen through European conquest and unequal exchange in resource extraction due to colonialism. As they write, "Simply, if historical drivers of present injustices are not specifically factored into understandings of the present, and preferences and projections about the future, then they will affect (most likely negatively) the implementation of those preferences and projections" (Golub et al., 2013, p. 275).[2]

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[2] This type of historical context is difficult to find in most literature about LIBs and clean energy minerals, though it is vital to our understanding of the present situation. For example, the Democratic Republic of Congo's problematic cobalt mining industry was originally established under King Leopold of Belgium in one of the most violent colonial regimes in history (Nzongola-Ntalaja 2002; Gulley 2022). However, while many articles, media coverage, and

In this chapter, I analyze the Lithium Valley development through the lens of energy justice to generate insights that can broadly inform the equitable development of clean energy mineral supply chains. My research questions are: (1) what are the energy justice implications of developing a geothermal lithium industry in the Salton Sea region, including distributive, procedural, recognition, and restorative justice? And (2) what lessons can be learned to support environmental justice in this development and others, in terms of positive examples (i.e., novel initiatives) and challenges?

Environmental justice scholarship is complex and varied, with varying interpretations and recommended approaches (Pellow, 2000). My intent is not to assert new or improved definitions of environmental justice but to generate actionable insights about this development using my understanding of energy justice dimensions as a guiding framework.

The rest of the chapter is structured as follows. First, I provide more background on the historical, environmental, and social context of the Salton Sea region and the geothermal and lithium resources in the Salton Sea Geothermal Field. The following section identifies stakeholders' concerns and priorities about the development using observation of community meetings and content analysis of public meeting transcripts. Guided by the content analysis results, I analyze the development's distributive, procedural, recognition-based, and restorative justice implications and identify opportunities and challenges. I discuss the potential impacts and benefits, opportunities for the public to participate in decision-making processes regarding Lithium Valley, and the provision of accessible

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industry sources point out the human rights abuses associated with cobalt mining, colonialism is rarely ever mentioned (e.g., Arvidsson, Chordia, and Nordelöf 2022; Thies et al. 2019; Sovacool 2019; Maiotti and Katz 2019).

information, highlighting lessons likely to surface in other clean energy developments. Finally, I discuss the limitations of this study and identify recommendations for policymakers and researchers to support environmental justice when developing clean energy supply chains.

Background on "Lithium Valley"

This section provides context about the development, including the regional history, environmental conditions, and socioeconomic characteristics that shape the present situation. The information presented is based on multiple visits to the region, tours organized by a community-based organization (Comitéé Civico del Valle), observations of public and community meetings, analysis of public comments submitted to the Lithium Valley Commission docket (California Energy Commission, n.d.-b), conversations with community members and representatives from local advocacy organizations, and review of available literature, including historical archives about the Salton Sea. This text was first published in Dobson et al. (2023), except for the information about Native American tribes, which I have expanded.

Historical Context: Agriculture, Salton Sea Water Levels, and Public Health

The area now partially covered by the Salton Sea was historically known as the Cahuilla desert. It is a natural basin that has periodically filled with water and evaporated over millennia as the Colorado River changes course, temporarily forming a body of water called Lake Cahuilla. The modern Salton Sea was formed in 1905, when a year of heavy rains caused the Colorado River to breach a canal, dumping water into the Cahuilla basin. The river deposited mineral sediments over time, including lithium, which made their way into the subsurface and mixed with hot brine in the subsurface.

The soil in the region is fertile after millennia of sediment deposits from the Colorado River, and most of the modern towns in Imperial County were established in the early 1900s to support the growing agricultural industry (Morton, 1977). Niland was formed in an area of citrus plants, Calipatria was established to grow peas and process alfalfa, and Brawley was developed to distribute agricultural products. More than a century later, the agriculture industry has the highest economic output and is the second-largest employer in Imperial County (Langholz & DePaolis, 2021).

In the 1950s, the salinity of the Salton Sea had reached a level similar to the ocean, and the California Department of Fish and Wildlife (then known as the Department of Fish and Game) transplanted a variety of fish from the Gulf of California (Walker, 1961). The Salton Sea became a thriving recreational scene, and the towns of Bombay Beach, North Shore, and Salton City emerged from the resulting tourism industry. The insects, wetlands, and fish attracted migrating bird populations, and the Salton Sea became an important stopover point along the Pacific flyway (Jones et al., 2019).

Throughout the 20th century, the Salton Sea's water level was primarily maintained by agricultural runoff from the surrounding fields. Then, in 2003, the local water utility initiated a water transfer of 300,000 acre-feet per year (AFY) to urban coastal areas, which was enabled by water conservation measures from agriculture (Thrash & Hanlon, 2019). For 15 years, fallow fields provided mitigating inflows of 200,000 AFY to the Salton Sea, but these expired in 2018. Consequently, lake levels began to drop precipitously in 2018.

The declining lake levels expose more of the lakebed, or "playa," which creates severe public health issues due to dust that is kicked up during wind events (Johnston et al., 2019). Air quality in the region is also affected by dust and emissions from agriculture and trucking, particularly around the Calexico/Mexicali border crossing (Mendoza et al., 2010). Estimated asthma rates in Imperial County are around 12% for the total population and 19% for children under 17, compared to statewide rates of 9% and 10% (California Department of Public Health, n.d.). At the same time, evaporation causes the salinity of the Salton Sea to increase; it is currently 60 parts per thousand, nearly twice as high as the Pacific Ocean (Salton Sea Authority, n.d.). This high salinity has caused many fish species to die, negatively impacting migratory bird populations (Fogel et al., 2021). As part of the Salton Sea Management Plan, California is implementing species habitat conservation and dust suppression projects to mitigate air quality issues and improve the situation for nearby communities and the environment.

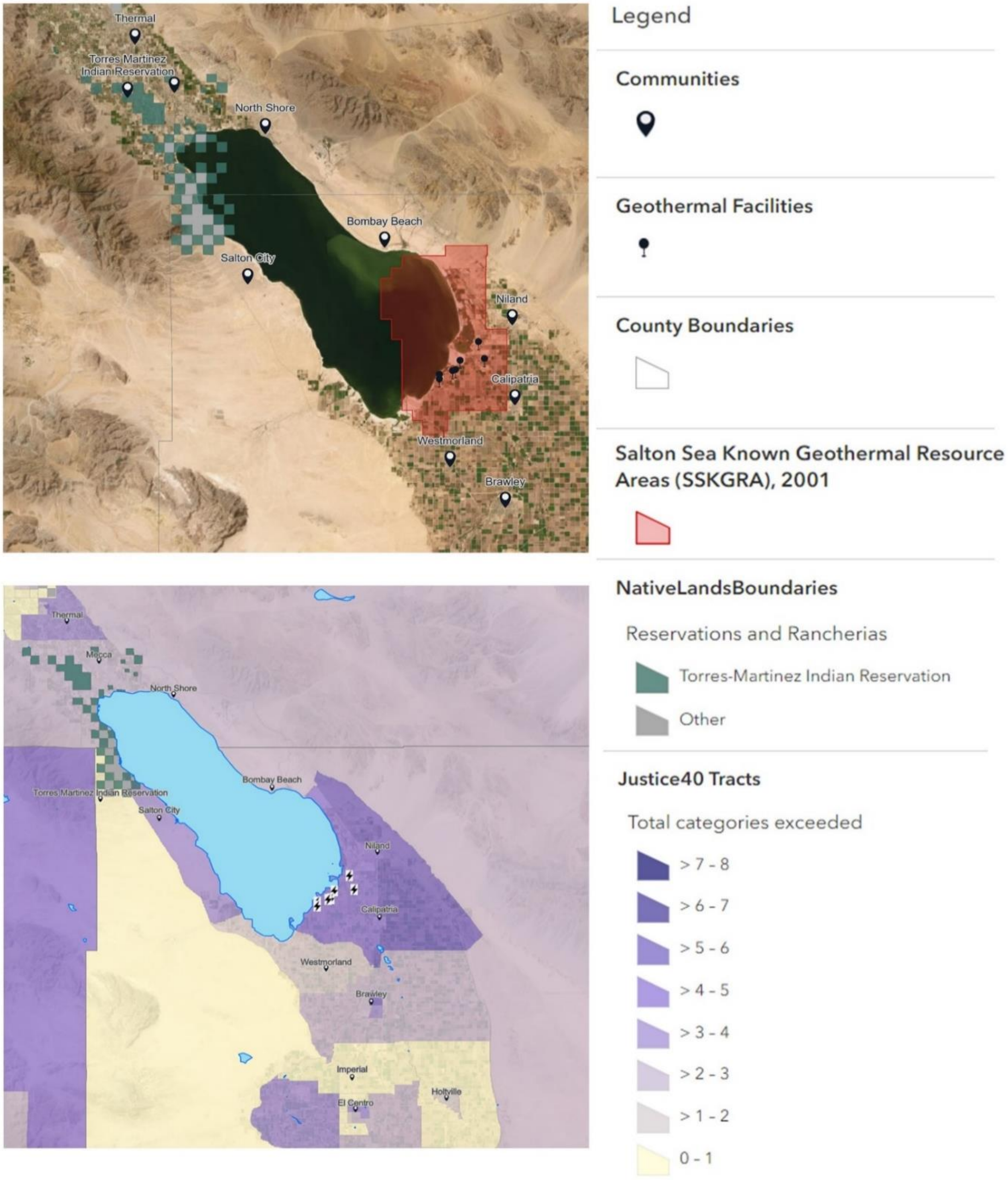

Figure 1: Map of the Salton Sea Geothermal Resource Area and surrounding communities (top), with layers showing tribal lands and environmental burden indicators (bottom) according to the Justice40 Initiative criteria (Council on Environmental Quality; California Technology Agency/GIS Unit).

Frontline Communities

The Salton Sea is between Riverside County on the North end and Imperial County to the South (Figure 1). There are approximately 180,000 residents in Imperial County, the vast majority (85%) of whom are Hispanic or Latino, with 77% speaking a language other than English at home (United States Census Bureau, n.d.-a). However, this may be an underestimate, as Hispanic populations have historically been undercounted by the United States Census, particularly in 2020 (Khubba et al., 2022). Indeed, demographers consider Imperial County to be one of the most challenging places to count in California because a high proportion of the population is from historically undercounted groups, many people live in remote housing locations, and there is limited internet access (Thorman et al., 2019). Agriculture is one of the largest sources of employment in the region (Southern California Association of Governments, 2019). Since so many people work outdoors, air quality and extreme heat are of paramount concern.

The Salton Sea Geothermal Field is on the north end of Imperial County, which has seen a declining population as communities face extreme challenges related to poverty, unemployment, and public health (Nava-Froelich, 2023). The census tracts in this area (Figure 1.6) are designated as disadvantaged communities by the California Environmental Protection Agency and federal Justice40 Initiative criteria (CalEnviroScreen 4.0, 2021; Council on Environmental Quality, 2024). No communities are immediately adjacent to existing geothermal facilities, as the nearest towns are roughly four miles away (Table 1.1). However, several communities can be considered “frontline communities” as they (a) stand to be impacted by infrastructure, traffic, and social changes, (b) share a dependence on the same water source, or (c) share the same air basin (DOE, 2022)).

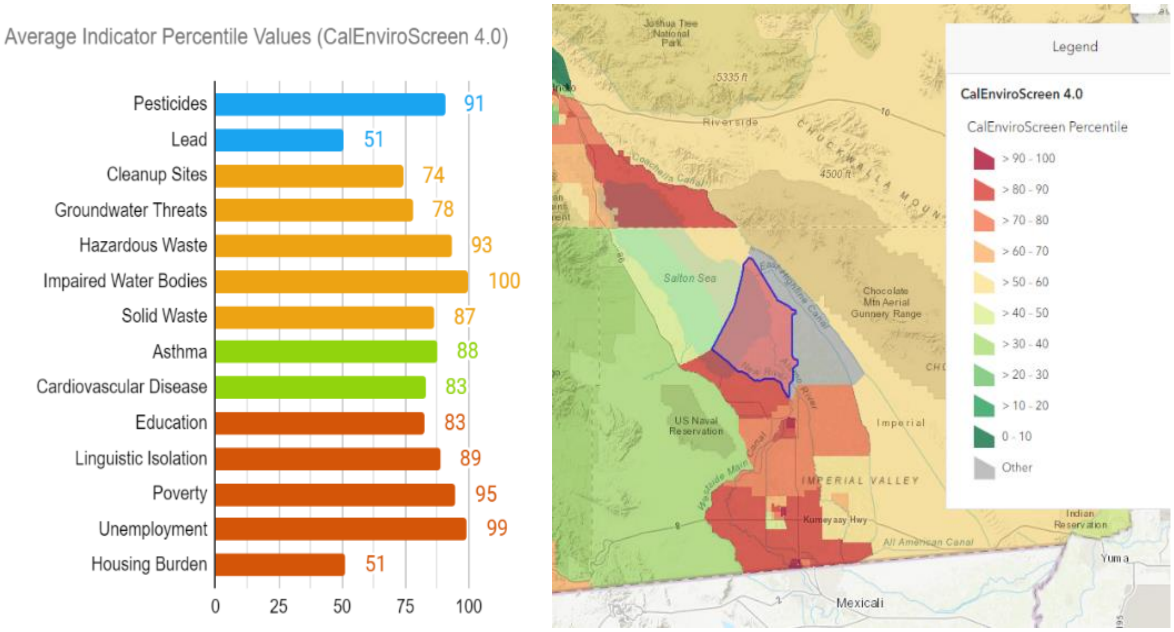

Figure 1.2: Cal EnviroScreen 4.0 results for the census tract surrounding Niland, Calipatria, and Westmorland. The percentile values represent the percentage of areas in the state of California that have a lower value for that indicator.

These are also frontline communities in terms of the impacts of climate change. The Georgetown Climate Center offers the following definition: “Frontline communities include people who are both highly exposed to climate risks (because of the places they live and the projected changes expected to occur in those places) and have fewer resources, capacity, safety nets, or political power to respond to those risks (e.g., these people may lack insurance or savings, hold inflexible jobs, exert low levels of influence over elected officials, etc.” (Georgetown Climate Center, n.d.). The communities surrounding the SSGF all fit this definition, as they are impacted by heat and drought conditions that are expected to worsen due to climate change (Maizlish et al., 2017). Furthermore, with a high proportion of low-income and Latino households, the communities are vulnerable to environmental burdens and face structural barriers to healthcare and political participation, such as language and documentation status (Cheney et al., 2022).

Table 1.1: Frontline Communities Near the Salton Sea Known Geothermal Resource Area

Name	Distance to closest geothermal facility*	Distance to SS-KGRA	Justice40 Environmental Burden thresholds exceeded**
Niland	4.04 miles	0.63 miles	Energy, health, legacy pollution, waste and wastewater, workforce development
Calipatria	4.76 miles	0.78 miles	Energy, health, legacy pollution, waste and wastewater, workforce development
Westmorland	7.91 miles	2.65 miles	Housing, workforce development
Brawley	13.45 miles	8.84 miles	Climate change, health, housing, legacy pollution, waste and wastewater, workforce development
Bombay Beach	13.48 miles	1.89 miles	Energy, health, legacy pollution
Salton City	20.7 miles	12.71 miles	Energy, legacy pollution, transportation, workforce development
North Shore	29.4 miles	17.71 miles	Energy, legacy pollution, workforce development
Torres Martinez Reservation	27.85 miles	19.63 miles	Climate change, housing, workforce development

*Refers to straight line distance calculated using ArcGIS, not driving distance.
**See the Justice40 environmental burden methodology for details (Council on Environmental Quality, 2024).

Native American Tribes

Indigenous people have inhabited the region for millennia, with evidence of complex trade networks, wells, and settlements dating back at least 10,000 years (Gates & Crawford, 2010; Shackley, 2019). The Northern half of the Cahuilla basin is the ancestral homeland of the Desert Cahuilla Indians, who migrated seasonally between the desert, foothills, and mountains. The region was also traversed and inhabited by the Quechan, Cocopah, and Kumeyaay (Voyles, 2021). The reservations in the area today were established away from population centers shortly after California became a US state amidst an onslaught of settler colonialism catalyzed by ranching and the gold rush. As Natale Zappia writes:

> Without question, the gold rush proved disastrous for Natives across the northern and southern parts of the newly admitted state of California. The dramatic influx of aggressive foreign settlers, miners, and ranchers with their accompanying diseases, coupled with extensive droughts, all undermined the power and control that Native Californians had over their territory. (Zappia, 2014, p. 116)

There were complex political dynamics at this time, with Indigenous resistance against settlers as well as conflicts between different Indigenous groups. Furthermore, while the US negotiated a series of treaties to establish reservations, according to Zappia, "none of these became ratified, as the flood of miners and other immigrants refused to acknowledge any Indian rights" (Zappia, 2014, p. 116). During the late 1800s, Indigenous communities in California, including the Cahuilla, were oppressed by settlers through governmental control and extrajudicial violence, including accounts of lynching men and assaults on women (Voyles, 2021a).

Thus, while the proposed developments are not within official Indigenous reservation territory, these territories are a small fraction of their ancestral lands, and the Salton Sea and surrounding environment maintain cultural significance for Tribes in the region. One of the concerns raised by members of the Quechan and Kwaymii Tribes is a sacred site close to the geothermal facilities called Obsidian Butte, where Indigenous people sourced obsidian to make tools and use in religious ceremonies (Gates & Crawford, 2010; Naimark, 2023). As such, the affiliated Tribes expect meaningful government-to-government consultation regarding proposed lithium and geothermal developments, and tribal elders and representatives have made multiple public comments criticizing the development's lack of consultation (Imperial County Planning Commission, 2023).

Lithium and Geothermal Resources

The lithium resources are not in the lake itself but in the Salton Sea geothermal field, a deposit of high-temperature, mineral-rich brine thousands of feet below the Earth's surface near the Southern end of the lake in Imperial County. Currently, 11 geothermal power plants operate in the area, with a combined output of 340 megawatts (MW) (California Energy Commission, 2021). Based on the brine's mineral composition, these facilities are estimated to process an annual throughput of 127,750 metric tons (MT) of lithium carbonate equivalent (LCE), which represents eight times the quantity of US lithium consumption in 2019 (Jaskula, 2023; Warren, 2021). The lithium is currently reinjected into the geothermal reservoir, along with other minerals in the spent brine.

Geologists knew about Imperial County's mineral-rich geothermal brines long before the region's first geothermal power plant was developed. Operators first explored the possibility of extracting minerals in the 1960s (Morton, 1977). Decades later, CalEnergy had a commercial plant operating between 2000 and 2004 to extract zinc from produced brines (Clutter, 2000). However, it abandoned the effort because technical challenges prevented it from being economically viable (Berkshire Hathaway Inc., 2005). The first company to demonstrate lithium extraction was Simbol Materials, which started operating a demonstration plant in Calipatria in 2011 (Biello, 2011; Simbol Materials, 2011). In 2013, the company announced that it successfully produced high-purity lithium carbonate from geothermal brine and planned to build a commercial plant to begin operation in 2015 (Green Car Congress, 2013). Despite this, Simbol abruptly closed in 2015 (Roth, 2015).

Today, three companies, EnergySource Minerals (ESM), Berkshire Hathaway Energy Renewables (BHER), and Controlled Thermal Resources (CTR), plan to pursue lithium extraction as an addition to existing geothermal plants or by building a new geothermal and lithium extraction facility (Paz et al., 2022). Major automakers have also announced contractual agreements to offtake lithium supplied by geothermal DLE (Wilson, 2021). However, the technology is still in the early stages, and the upcoming planned developments will be at the pilot scale.

Community-Based Organizations (CBOs).

There is a network of community-based organizations (CBOs) and non-profits that advocate for disadvantaged communities in Imperial County and the Eastern Coachella Valley (Table 1.2). These range from well-established advocacy organizations like Comitéé Civico del Valle, which has operated in Imperial County for decades, to smaller grassroots groups like Northend Alliance 111 and the Bombay Beach Community Services District that organize basic infrastructure and services in their respective communities. Along with public health, CBOs in this region work on issues related to the US-Mexico border, farmworker rights, and housing. They are actively involved in Lithium Valley development, sharing information about how to participate with residents and advocating for environmental protections and a fair distribution of benefits.

Table 1.2: Selection of Community-Based Organizations (CBOs) in the Salton Sea Region

Organization	**Website**
Comité Civico del Valle	https://www.ccvhealth.org/
Northend Alliance 111	NA
Bombay Beach Community Services District	https://www.bbcsd.org/
Imperial Valley Equity and Justice	http://ivequityjustice.org/
Los Amigos de la Comunidad IV	https://losamigosdelacomunidad.com/
Raízes, Inc.	https://raizesinc.org/
Imperial Valley LGBT Center	https://ivlgbtcenter.com/
Alianza Coachella Valley	https://www.alianzacv.org/
Leadership Counsel for Justice and Accountability	https://leadershipcounsel.org/

Methods

I used content analysis of LVC transcripts and community meetings to identify relevant topics and priorities for stakeholders that influence or are impacted by this development. The methods for content analysis are described below. To analyze distributive justice, I reviewed available literature about the potential environmental impacts of DLE and geothermal, guided by the stakeholder priorities identified in the content analysis. I also discuss the possible benefits and mechanisms implemented or recommended to ensure they accrue to local communities. The content analysis informs my discussion of procedural justice. I compare the content of community-focused and state-led meetings to see how closely aligned the two are; do state-led discussions address topics that are high priorities for local community members? Additionally, I discuss the measures to facilitate public participation and the provision of accessible information, an essential requirement of procedural justice (Ottinger, 2013).

My discussion of recognition and restorative justice is primarily based on literature review. I identify key themes and questions from environmental justice scholarship about recognition and restorative justice and discuss how they might apply to Lithium Valley. For more in-depth qualitative research about procedural and environmental justice in lithium extraction, I refer readers to two insightful master's theses: Buss (2022) and Iyer (2023). Buss (2022) examines community experiences of the Lithium Valley development using semi-structured interviews.

My perspective is informed by my experience as a member of a research team commissioned by DOE to study lithium and geothermal resources in the Salton Sea region, including the potential environmental impacts (Dobson et al., 2023). I was responsible for integrating community engagement into the project. My position in relation to this topic is therefore that of an outsider to the region; however, through this role, I have participated in symposiums, meetings, and other relevant proceedings related to Lithium Valley, granting me access to policymakers, companies, and other stakeholders who hold power in the development. Because of this experience, I have a much deeper technical understanding of DLE and geothermal than I could have achieved on my own, as I could and did ask the scientists on the team numerous questions whenever I didn't understand a concept. The access to stakeholders and the decision-making process also informs my understanding of practical barriers to achieving environmental justice, an understanding that, for better or worse, is perhaps more sympathetic to institutions that hold power than other academic critiques of green extractivism.

The goals, activities, and feedback on the community engagement effort is described in Chapter 12 of Dobson et al., 2023. I refer the reader to this document for more reflections on the process, critiques we received, and lessons learned (of which there were many).

Content Analysis

Content analysis refers to the systematic coding and analysis of documented communication. It has been used extensively across disciplines for diverse purposes, including understanding the focus of a group or institution and identifying themes or trends (Downe-Wamboldt, 1992; Krippendorff & Klaus, 2019; Russell Bernard et al., 2016). Environmental researchers have deployed content analysis of public meeting minutes to understand stakeholder engagement and perspectives (Gamborg et al., 2019; Nguyen Long et al., 2019; Sullivan et al., 2019).

Data sources for content analysis.

Lithium Valley Commission. In September 2020, the California Governor signed AB 1657, which convened a Blue-Ribbon Commission ("Commission") of 14 appointees charged with "reviewing, investigating, and analyzing certain issues and potential incentives … regarding lithium extraction and use in California" (State Energy Resources Conservation and Development Commission: Blue Ribbon Commission on Lithium Extraction in California, 2020). The Commission, known colloquially as the 'Lithium Valley Commission' (LVC), comprises representatives from various state agencies and levels of government, the geothermal industry, community advocacy organizations, an environmental organization, and the tribal councils of two Indigenous communities. It was coordinated by the California Energy Commission (CEC). The LVC's final report was released in November 2022 (Paz et al., 2022).

The meetings were held monthly from 1:30-5:00 pm. Due to the COVID-19 pandemic, all meetings took place virtually using a webinar format, with an option to hear simultaneous interpretation in Spanish. Beginning in May 2022, the meetings were hybrid, with four locations offering the option to attend an in-person livestream. Typically, the meetings consisted of discussions and updates from the commissioners, followed by presentations on pre-defined topics by invited speakers, with opportunities for public comment following each agenda item. Public comment is limited to three minutes per speaker. The meetings were recorded, transcribed, and posted to the LVC's webpage (California Energy Commission, n.d.-b). To inform this analysis, I downloaded and analyzed publicly available transcripts from nine LVC meetings (February through October 2021) from the California Energy Commission website (California Energy Commission n.d.).

Community Meetings. To further understand the concerns and priorities of residents, I attended seven community meetings. Three were organized by the Leadership Counsel for Justice and Accountability, a community-based environmental justice organization that works with communities in the Eastern Coachella Valley (Leadership Counsel, 2016). As the meetings were not recorded, the organizers and I took detailed notes to record the questions asked by participants. In addition, I tabulated questions from four community forums held by the LVC, one in November 2021 and three in October 2022 after the Commission's draft report was released. Details about the purpose, format, attendance, and questions asked during each meeting are provided in the Appendix (A1.2).

Thematic coding. A list of themes related to specific environmental and socioeconomic impacts and community engagement was developed based on literature about environmental justice and social responsibility in mineral extraction (Table 1.3). Frequent points of discussion during LVC meetings and questions from community meetings were then categorized within the themes identified where applicable or into new themes if they had not emerged in the literature review. After developing the final list of themes, I selected associated keywords and coded the LVC transcripts using the text search function of Atlas.ti, a qualitative software (ATLAS.ti, 2022; Table 3). The text was coded using the "or" operator, including the inflected forms for each keyword. For example, the code "air quality" was applied to all lines containing "air" or "pollution" or "local emissions" or "dust" or "particulate matter" or "criteria pollutant." Finally, the corresponding coded text and questions were explored, and an additional subcode was applied based on the context in which they were mentioned. The codes were reviewed by another researcher (N. Helal) for accuracy. The complete codebook, which includes the logic for assigning contextual subcodes and results for each subcode, is provided in the Appendix (A1.1).

Table 1.3: Thematic codes and associated keywords from Lithium Valley Commission transcripts and Community Meetings.

Topic	**Keywords**	**Source**
Air quality	Air, dust, particulate matter, PM, NOx, SOx, ozone	Evans & Kantrowitz, 2002
Waste stream	Waste, byproduct	Flexer et al., 2018
Climate	Climate, carbon, greenhouse gas, GHG, CO2, global warming	LVC
Local ecology	Ecosystem, habitat, conservation, playa, restoration, species	Kramarz et al., 2021
Water	Water, acre feet, gallon	Liu & Agusdinata, 2021; Lorca et al., 2022; Urkidi & Walter, 2011
Seismicity	Seismicity, seismic, tectonic, earthquake, San Andreas	Community meetings
Emergency plan	Emergency, worst-case scenario, disaster	Community meetings
Public health	Health, healthcare, illness, disease	Brulle & Pellow, 2006
Infrastructure	infrastructure, broadband, rail, road	Kaswan, 2020; Mancini & Sala,

		2018
Employment	Employ, employment, jobs, workforce, training, skilled, unemployment, union	Mancini & Sala, 2018
Housing affordability	Housing, cost of living, affordability, property value	Mancini & Sala, 2018; Community meetings
Community engagement	Participation, community engagement, outreach, procedural justice	LVC, Community meetings

Results

Distributive Justice

In this section, I discuss the potential impacts of geothermal and DLE, guided by the content analysis of State-led and community-focused meetings. The local community's highest priorities were water (n=16), public health (n=16), and employment (n=16), as indicated by the number of questions asked (n). Meanwhile, the LVC's most frequently discussed topics were water (n=295), employment (n=260), and infrastructure (n=95), as indicated by the word count analysis (Figure 3).

For each topic, I describe how it was discussed in both contexts, then analyze the potential impact based on available literature. For benefits, I also discuss what steps, if any, are being taken to ensure they accrue to frontline communities. My primary sources of information are a draft environmental impact report (DEIR) prepared for EnergySource Minerals (Chambers Group, Inc., 2021); a pilot study funded by the Department of Energy's Geothermal Technologies Office (Dobson et al., 2023); and a report about Environmental Justice in Lithium Valley prepared by Earthworks, a global non-profit, in collaboration with Comité Civico del Valle, a community-based advocacy organization (Naimark et al., 2023). These sources are discussed further in the procedural justice section (Table 1.4).

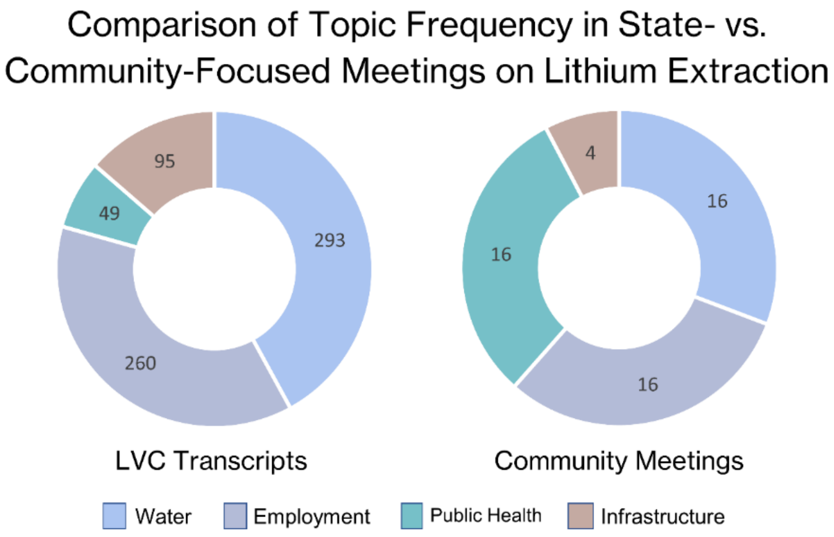

Figure 1.3: Comparison of topic frequency in state-led vs. community-focused meetings. The numbers refer to associated keyword mentions for LVC transcripts and related questions for community meetings.

Environmental and health impacts.

Water. For both groups, water was the most frequently mentioned environmental topic (Figure 1.3). Community members' most frequent questions were about the source of water that would support DLE (n=5), the quantity of water consumed by the process (n=4), and whether DLE would impact local water quality (n=2). By contrast, the LVC mainly discussed water in the context of regional policy and management, such as water rights allocation and required permits (n=124). Where the LVC discussed consumption, it was primarily to highlight the sustainability of DLE (n=62) more so than to examine its expected water consumption (n=30), indicating a lack of alignment with the community's concerns (Figure 1.4). However, regional policy and management are also relevant to environmental justice, if indirectly, and relate to the community's questions about DLE's water source.

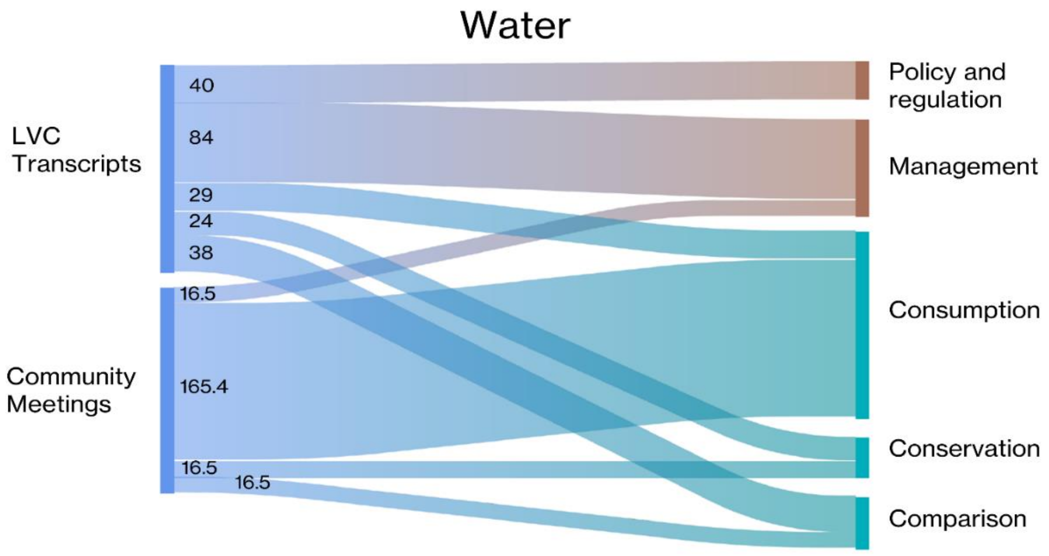

Figure 1.4: Breakdown of how water was discussed in community-focused and LVC meetings, normalized by the total number of coded quotations in each document group.

The primary source of water for Imperial Valley is the Colorado River, as groundwater in the region is considered unsuitable for human consumption or irrigation due to its high salinity (Montazar, n.d.). The water supply is managed by the Imperial Irrigation District (IID), a local utility that has an annual Colorado River water allocation of 3.1 million AFY. Approximately 97% is currently allocated to agriculture. The remaining 3% is divided between municipal and industrial uses, and the existing geothermal plants consume approximately 0.25% of the total allocation (Dobson et al., 2023). Alfalfa for cattle feed is one of the region's primary commodities, and the production of this commodity alone consumes an estimated 900,000 AFY (alfalfa consumes six acre-feet per acre, with over 150,000 acres harvested annually (Imperial County, 2020; Montazar, n.d.).

Any process water for new developments is likely to be purchased from this supply (Chambers Group, Inc., 2021; Imperial Irrigation District, 2012). IID has set aside 25,000 AFY for future industrial development, including geothermal energy and lithium production. 9,900 total has already been allocated to EnergySource Minerals and CTR for lithium extraction (Dobson et al., 2023), and BHER will need 13,165 AF for new geothermal energy facilities (BHE Renewables, 2023). Therefore, enough water is available to support the announced lithium extraction and energy operations without impacting water availability for agriculture or household consumption.

In the future, industrial demand may grow beyond the allocated capacity, and ongoing drought will most likely reduce IID's allocation of Colorado River water. In both cases, water would need to be reallocated from agriculture to support the expansion of geothermal or lithium. Dobson et al. (2023) estimate that the industry would represent 6% of IID's total current allocation if all planned geothermal and lithium extraction expansions were developed. Thus, even under "optimistic" development scenarios, the lithium and geothermal industry represents a relatively minor water demand compared to agriculture.

However, reallocating water from agriculture would require farms to implement water conservation measures, such as more efficient irrigation or fallowing fields. Because agricultural runoff is the main inflow to the Salton Sea, this could cause the Sea's evaporation to accelerate, exposing more of the lakebed and potentially exacerbating the related issues with dust, air quality, and public health (Naimark, 2023). While farm operators have historically been compensated when they need to let fields fallow (e.g., in the quantification settlement agreement), farmworkers who lose their jobs are not. Given the connection between agricultural runoff and the Salton Sea, the consumption of industrial developments would need to be analyzed collectively to understand the impact on Salton Sea water levels and mitigate any adverse impacts.

The uniquely sensitive situation regarding water elevates the importance of transparent and inclusive decision-making about how water is allocated. It also highlights the importance of conserving water during operations. During LVC meetings, representatives from each company indicated they would recycle water during their process. However, as the technology for DLE and water recycling is still under development, it is difficult to estimate the reductions that could be achieved through recycling.

Health and air quality. Participants in community forums asked about the impact of lithium and geothermal energy production on respiratory health, the byproducts generated by the process, whether the properties of lithium impact public health, and how health impacts would be monitored considering the existing public health crisis. In four meetings, participants commented that public health was non-negotiable and not an acceptable trade for money or employment; as a public commenter stated during the LVC's community forum, "jobs don't fix the health issue" (California Energy Commission, 2021b). Meanwhile, mentions of health-related keywords were lower in the LVC compared to topics like infrastructure or employment (Figure 1.5). Discussions of health in the LVC were related to the existing regional public health situation (n=14), mechanisms that protect public health, such as permits and regulatory oversight (n=14), and the potential for lithium development to help address the public health crisis (n=9). For example, tax revenue could fund public health infrastructure, or new facilities could mitigate dust by paving over exposed playa.

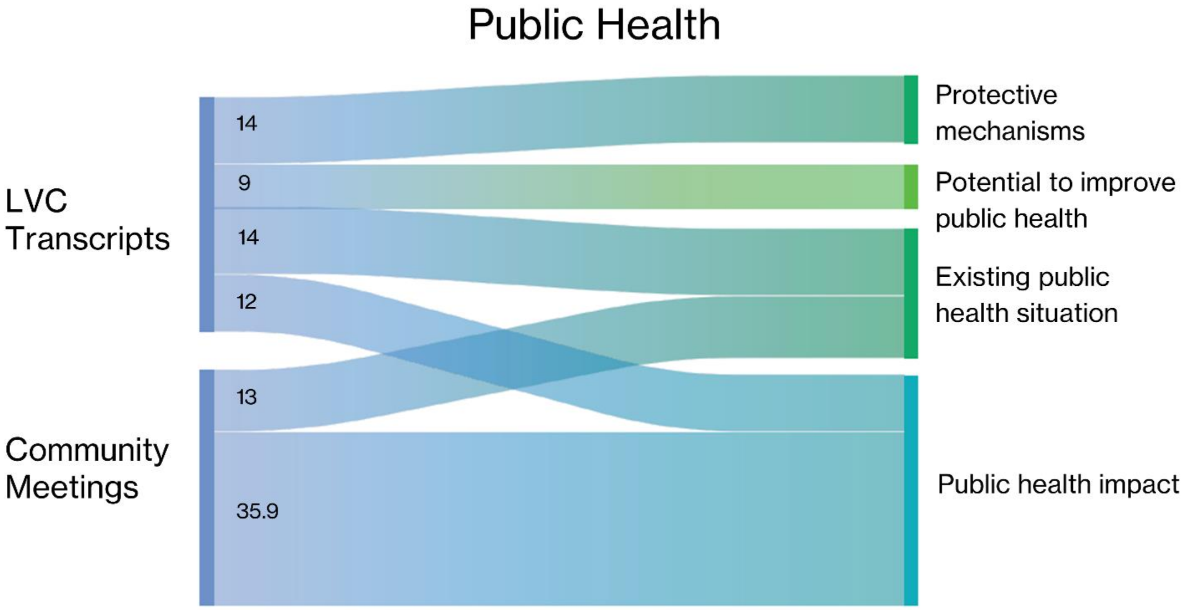

Figure 1.5: Breakdown of how public health was discussed in community and LVC meetings, normalized by the total number of coded quotations in each document group.

The impact on public health has not been studied since DLE is not commercially operational. However, some data about the potential air emissions is available, as well as emissions from geothermal facilities. Dobson et al. (2023) analyzed reported emissions from existing geothermal power plants, which emit non-condensable gases, specifically benzene, hydrogen sulfide, and ammonia. However, the amounts are significantly lower than those of other regional sources, including naturally occurring emissions from the Salton Sea. The report does not analyze how emissions might disperse or potentially impact ambient air quality in nearby communities.

Furthermore, most of the analysis focuses on emissions from geothermal sources because companies must report operational data to the state. For DLE, the report was limited to identifying potential sources of emissions. Here, the authors note that the onsite storage of hydrochloric acid could result in vapor emissions, which will require scrubbing. The other identified emissions occur during the product's drying, transfer, packaging, and final truck transfer, which are based on Chambers Group, Inc. (2021).

According to Chambers Group, Inc. (2021), the ESM facility's primary sources of air emissions are operational vehicles, stationary equipment, and trucks that will travel in and out of the project area. The estimated emissions are under the local air district's significance thresholds. However, the Salton Sea Air Basin is currently in nonattainment of criteria pollutant levels for ozone and $PM_{10,}$ according to the California Air Resources Board (CARB, 2019).

Waste. Participants in both community meetings (n=2) and the LVC (n=21) asked questions about the waste stream from DLE and the management of byproducts. Geothermal and DLE operations both generate solid waste when clarifying the brine. Most byproducts can be reinjected into the brine reservoir, but the impurity removal process precipitates a filter cake of silica and iron with "lesser concentrations of arsenic, barium, and lead" (Featherstone et al., 2020). According to Chambers et al. (2021), approximately 136,200 MT of iron-silicate material will be processed annually for a facility producing 20,000 MT LiOH. Dobson et al. estimate that if all the lithium were extracted from brine flowing through power plants today, it would generate 889,000 MT of solid waste annually.

This material is tested and disposed of at one of several facilities depending on whether it exceeds hazardous waste thresholds; if it exceeds California's threshold, it is sent to an industrial landfill in Yuma, Arizona, and if it exceeds federal standards, it is sent to a hazardous waste facility in Button Willow, California. Chambers Group, Inc. (2021) estimates that up to 10% of trucks carrying waste from the process would be delivered to a waste treatment facility in Arizona. Under California law, there are also requirements and plans in the DEIR for onsite storage of byproducts and waste.

Transparency and accountability to ensure waste is handled safely can help mitigate any potential negative impacts (Naimark, 2023). The burden could also be reduced by identifying productive uses for the mineral byproducts or methods to avoid precipitating harmful compounds.

Seismicity. The community asked about lithium extraction's impact on the region's seismicity, as the Salton Sea Geothermal Field is near the San Andreas fault (n=2). This issue continues to arise in workshops and public comments. Dobson et al. (2023) examined the correlation between geothermal production and seismicity rates, finding that low-level seismicity rates increased following the onset of geothermal production but leveled out in the early 2000s. They are now similar to seismicity rates in the overall region. In other studies, geothermal energy production has been observed to influence seismicity due to fluid production and reinjection to the reservoir (Brodsky & Lajoie, 2013).

Lithium extraction occurs after fluid has already been withdrawn and is not expected to impact seismic activity. However, clear guidance and precautions are necessary to avoid siting new production or reinjection wells near active faults. Another mechanism that could help build trust is transparent monitoring; for example, the Geysers geothermal development in Northern California has a Seismic Monitoring Advisory Committee that meets biannually and is open to the public (Calpine, n.d.). To date, no plans for publicly accessible monitoring have been announced.

Other themes. Several other environmental topics were discussed in one or both settings:

- Local ecology: The community asked about the impact of lithium extraction on the soil (n=1) and how lithium extraction could support the restoration of the Salton Sea (n=1). The LVC primarily discussed ongoing restoration efforts in the region (n=48), including the importance of the geothermal and lithium industries complementing those efforts (n=30).
- GHG emissions: The LVC discussed the strategic role of lithium and geothermal in meeting California's climate goals.
- Finally, participants at community meetings asked about the impact a new industry could have on the cost of living (n=1) and what the "worst-case scenario" for an accident at an extraction facility might be (n=2).

Community benefits

Employment. Employment represented an area of alignment between the two groups. The most frequently discussed subcategory in both groups was workforce development, followed by job creation and quality (Figure 1.6). Community members asked what programs would be available to ensure residents were qualified and which residents would be eligible for training programs (n=10). Meanwhile, LVC commissioners discussed the workforce needs of the lithium and geothermal industry (n=74) and how to develop local capacity (n=88). Participants in both groups brought up the local community's experience with previous industries, which promised employment opportunities that did not materialize (California Energy Commission, 2021c, p. 49). For example, solar energy developments used public incentives and displaced agricultural land, effectively displacing a more reliable source of employment.

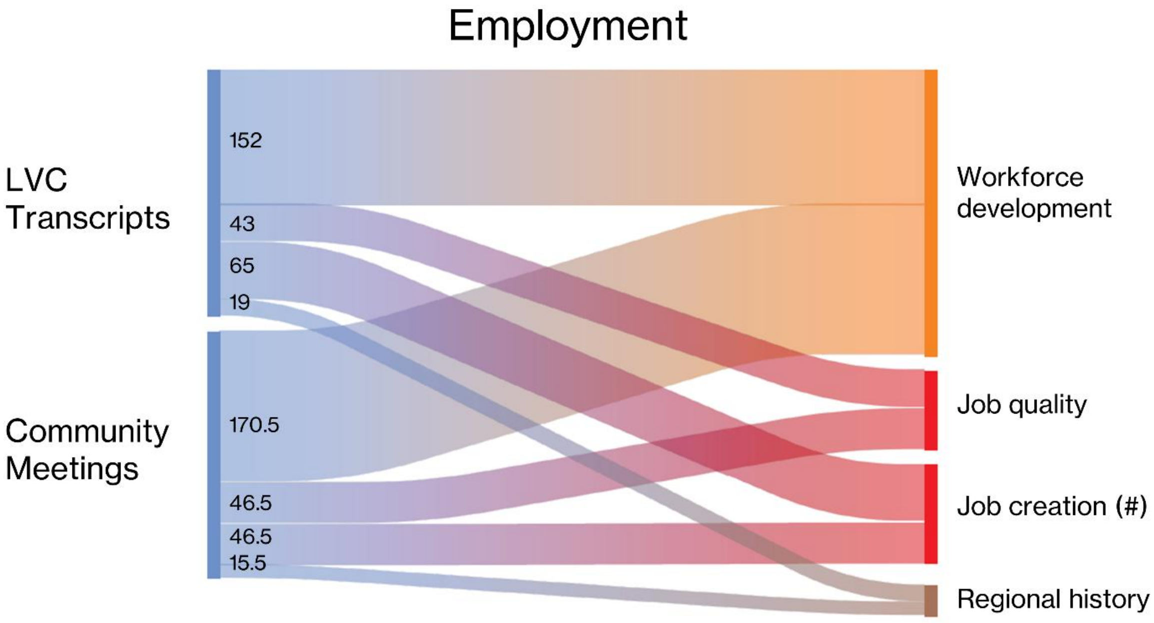

Figure 1.6: Breakdown of how employment was discussed in community and LVC meetings, normalized by the total number of coded quotations in each document group. This figure illustrates an alignment in employment-related topics.

Employment is often the principal benefit attributed to or used to justify industrial development. However, job creation alone is insufficient to verify a meaningful community benefit. More information is needed about the quality of jobs and whether companies hire locally instead of "importing" the workforce (Liu & Agusdinata, 2020; Mancini & Sala, 2018; Mulvaney, 2014). Examining employment in greater depth is, therefore, fundamental to distributive justice.

Several efforts are underway to prepare the local workforce for jobs in the lithium industry (Benner et al., 2024). The local community college, Imperial Valley College (IVC), is developing three certificate programs to prepare students for anticipated jobs: plant operator, instrumentation technician, and chemical laboratory technician. These programs are designed with input and support from companies. San Diego State University is also building a STEM campus in Brawley with funding from the state to train students in relevant fields like chemistry and engineering. Additionally, Imperial County ("County") commissioned a study to identify workforce gaps in ancillary industries such as hospitality, logistics, and manufacturing. Finally, labor unions have supported the development but stressed the importance of implementing project labor agreements (PLAs) to ensure that new jobs are union jobs with benefits and worker protections (Browning, 2022). The new CTR development includes a project labor agreement (Dial, 2024); however, state policy does not currently require measures such as local hire or apprenticeships (Benner et al., 2024).

One challenge raised during LVC community forums is that residents may struggle to access workforce development opportunities, particularly in the North End communities closest to the geothermal and lithium facilities (Appendix A.1.2: Meeting #5). Imperial Valley College is in El Centro, a 30-minute drive from the frontline communities of Niland, Calipatria, and Westmorland, and public transportation in the area is minimal. Participants in community meetings also asked whether undocumented community members would be eligible and if jobs and training would be accessible to older people, not only younger college students.

Infrastructure. Infrastructure was a high-priority topic during LVC meetings. Discussions of infrastructure addressed both what was needed to support new industries (n=57) and what was required by the community (n=27). Participants noted several areas where the development of new infrastructure could be mutually beneficial. For instance, industry will require improved roads, which could improve regional mobility, and better internet access, a known local issue: for example, during the COVID-19 pandemic, students faced disproportionate challenges accessing online learning (Fitzgerald, 2020).

A related socioeconomic impact is housing availability and affordability. In one community meeting, residents asked if the cost of living would increase because of the new industry. Research studying the impact of mining on communities following a coal boom found that, in several cases, an inadequate supply of permanent housing contributed to rising rental prices and affordability for communities near the resource (Petkova, 2009). Proactive planning for climate-resilient affordable housing could help mitigate this issue and prevent community members from being displaced due to a lithium boom.

Finally, the LVC discussed the potential for Lithium Valley to become a supply hub for LIBs by co-locating value chain production infrastructure, which would offer environmental and strategic benefits. Co-locating more production infrastructure would also multiply the opportunities for job creation and workforce development, though again, the "who" and "how" are still essential to consider for manufacturing. On the other hand, residents expressed concern about designating the area as an industrial zone, which could create an influx of traffic and pollution from production and warehouse infrastructure that would disproportionately burden the communities closest to the development and transportation corridors.

Tax revenue. Tax revenue is the principal mechanism for distributing benefits from lithium extraction to local communities (Heffron, 2020). On June 30, 2022, the Governor approved Senate Bill 125 (SB 125), establishing the Lithium Extraction Tax Law ("Lithium Tax"). The Lithium Tax requires producers to pay an excise tax per metric ton of lithium carbonate equivalent for any lithium produced in the state (CA Senate Budget and Fiscal Review Committee, 2022). Section 47100a specifies that 80% of the tax revenue must be disbursed to the county where lithium is produced, with at least 30% of the revenue in Imperial County being disbursed to "communities that are most directly and indirectly impacted by the lithium extraction activities." Public comments about where to invest revenue from the Lithium Tax are accessible online (Imperial County, 2023). The remaining 20% of tax revenue is directed to Salton Sea restoration, which could mitigate or even improve the issues related to lake levels and public health. SB 125 was passed after a coordinated advocacy effort from a broad coalition of CBOs, labor unions, environmental organizations, and the County (Lithium Valley Community Coalition, n.d.).

The Lithium Tax takes an unprecedented step toward codifying distributional justice by specifying that revenue must be invested in communities impacted by extraction. However, whether the revenue is invested to benefit frontline communities depends on the County's decision-making process and how they incorporate community feedback.

The community benefit also depends on whether there is money to invest in the first place. Local government and economic development representatives have pointed out that the industry must first succeed in generating revenue, which is not guaranteed, given the cost and technical challenges associated with DLE (Meyer, 2024). Furthermore, in November 2024, Californians will vote on a statewide ballot measure that would repeal the lithium tax (Salata, 2024).

Procedural Justice

As defined by Sovacool & Dworkin (2015), procedural justice "is concerned with how decisions are made in the pursuit of social goals, or who is involved and has influence in decision-making" (p. 437). Including local knowledge in decision-making and transparency regarding how public participation can shape the outcome are essential (Schlosberg, 2007). Upholding procedural justice also requires providing information in an appropriate form, including language interpretation and demystifying technical jargon if needed (Edge et al., 2020; Pearsall & Pierce, 2010).

In practice, procedural justice is constrained by knowledge asymmetries among stakeholders that influence the ability of different groups to participate in decision-making processes (Agusdinata et al., 2018; Kennedy et al., 2017). For instance, policymakers and industry stakeholders may have more information about the technology or resource underpinning a proposed development than local community members. Upholding procedural justice, therefore, requires providing accessible information about the anticipated impacts of a proposed development to all stakeholders, particularly frontline communities (Edge et al., 2020; Hampton, 1999; Pearsall & Pierce, 2010). However, the ability to do this is further limited by "undone science" and incomplete data on the local impacts of industrial processes, particularly on public health (Agusdinata et al., 2018; Frickel et al., 2010; Ottinger, 2013; Ottinger & Cohen, 2012).

Public participation and community engagement. There are various established methods for pursuing just outcomes in planning processes, which transportation justice scholars have categorized on a spectrum from state-centric to society-centric (Karner et al., 2020). The Lithium Valley Commission and subsequent public initiatives are examples of state-led public participation, which include public meetings, hearings, or opportunities to submit written comments. An identified strength of this approach is ensuring that the community's voice is heard. At the same time, one risk is a potential loss of trust if the process is perceived as unjust or unresponsive to community concerns (Karner et al., 2020).

The Lithium Valley Commission. As a public body, the LVC was subject to transparency laws requiring all meetings to be publicly noticed, and all documents presented or discussed during LVC meetings to be posted to a publicly available docket. Beyond complying with transparency laws, the CEC took several steps to make the process more accessible. The meetings and documents were translated into Spanish beginning in May 2021, and some documents and events were also translated into Purepecha. The LVC also held several in-person community forums during the evening to enable broader participation.

The first community forum in November 2021 followed the standard public meeting format of presentations and commissioner discussion with limited opportunity for public comment. The format prompted criticism from community advocates, who commented that engagement events should be more conversational and devote more time to listening to community members (e.g., Flores, 2021). The meeting format is a practical challenge for State-led procedural justice: state commissions are subject to the Bagley Keene Open Meeting Act, which places rules on how State agencies communicate and run public meetings ("Bagley Keene Open Meeting Act," 1967). While this promotes transparency, it limits flexibility and dialogue.

Around this time, several individuals and organizations submitted public comments with critical feedback about community participation more broadly. Comité Civico del Valle and other CBOs based in Imperial County stated that "it is felt that [equitable community engagement] is falling short at this time" (Comité Civico del Valle, 2021). Meanwhile, the Alianza Environmental Justice Campaign expressed a need for more clarity around environmental impacts and how the development would be regulated (Alianza Environmental Justice Campaign, 2021). In addition, they cautioned the LVC about the tone used to talk about the development:

> "Commissioners spoke about lithium extraction in positive light and suggested lithium extraction will happen despite the fact that adjacent Salton Sea communities have not given the same approval nor do we know if it will actually be sustainable without environmental impacts to water and air quality from the increased infrastructure and goods movement" (Alianza Environmental Justice Campaign, 2021, pg. 2).

During later community forums, the LVC changed its approach and followed a more listening-based format. These meetings were structured around small group discussions with professional mediation, enabling more meaningful dialogue. At the same time, the first model facilitates more transparency, as the public comments are all transcribed by a court reporter. While the community forums were transcribed, the breakout groups are not included; the documents state "begin small group discussion" and "end small group discussion" and then transcribe the facilitators' brief report-outs of what was discussed in their group.

Ultimately, the LVC's mandate was to write a report, which they fulfilled in December 2022. Since the LVC concluded, there has been no equivalent platform for members of the public to follow the development. Much of the action has now been transferred to the County. The County has a Lithium Valley website, and Board of Supervisors meetings are live-streamed and recorded; however, if lithium and geothermal are discussed, they are one of several other items on the agenda, making it more difficult to know exactly when these conversations will take place. The State and County can build on the progress achieved during the LVC by continuing to host regular public meetings about Lithium Valley and maintaining a centralized platform where people can access information.

Other State and County efforts. In addition to establishing the Lithium Extraction Tax, SB 125 allocated $5 million to Imperial County to prepare a programmatic environmental impact report (PEIR) and Specific Plan for Lithium Valley, which will include manufacturing and logistics in addition to lithium extraction (Imperial County, 2022). The PEIR is supported by Environmental Justice and Technical Advisory Groups, who held a community workshop. A workshop report and notes from both Technical Advisory Groups are available from the County's Lithium Valley website (Rick Engineering Company, 2023). There are additional opportunities to participate during each facility's permitting process, including a public review and comment period.

SB 125 also provided $800,000 to support community outreach and stakeholder engagement (Section 8 (c)(1)). Five CBOs (Comité Civico del Valle, Imperial Valley Equity and Justice Coalition, Los Amigos de la Comunidad IV, the Imperial Valley LGBTQ Center, and Raizes, Inc.) received funding from SB 125 to support outreach and gather community input for the Programmatic EIR and Specific Plan. The CBOs hold meetings where they share information about the development and how to submit public comments. For example, Imperial Valley Equity and Justice holds in-person community meetings in the evenings where they provide information about the programmatic EIR process and give people space to share how they want land use to be allocated.

Provision of Accessible Information. As discussed in the distributive justice section, there are three widely referenced sources of information that address the potential impacts of DLE in Lithium Valley: Dobson et al. (2023), which was a report commissioned by DOE; the draft EIR for

EnergySource Minerals (Chambers Group, Inc. (2021) and a report released by Comité Civico del Valle and Earthworks, a national global environmental justice advocacy organization, which was intended to inform community members (Naimark, 2023). These sources cover many high-priority community topics identified above (Table 1.4). However, there are still limitations and challenges to providing accessible information, which are discussed in this section.

Table 1.4: Sources of information about potential environmental impacts.

Topic	**Chambers Group, Inc. (2021)**	**Dobson et al., 2023**	**Naimark, 2023**
Water	Estimates water requirements for operation and construction. States that water supply is IID Colorado River water, applicant would be required to work with IID to manage any reduction in water availability.	Estimates water use for different production and drought scenarios based on announced IID allocations and the average use of existing geothermal facilities.	Estimates water demand for specified levels of lithium production considering announced IID allocations.
Air	Emissions from anticipated traffic and operational vehicles; use of hydrochloric acid and mitigation of HCl emissions.	Quantifies emissions from geothermal facilities (H2S, CO2, benzene, ammonia, PM), discusses potential air emissions from DLE based on Chambers Group, Inc. (2021).	Summarizes Chambers Group, Inc. (2021)
Waste	Estimates annual iron silica waste production from impurity removal.	Analyzes waste stream from geothermal based on manifests reported to state and county agencies; estimates anticipated waste for expanded lithium and geothermal production.	Discusses potential waste streams and management plans based on Chambers Group, Inc. (2021) highlights importance of transparent reporting.
Seismicity	Lists known seismic zones within 45-mile radius of project and standard mitigation measures; does not address well production or reinjection specifically.	Analyzes correlation between historic seismicity rates and geothermal energy production.	Discusses seismicity impacts of enhanced geothermal systems (EGS).

Most of the information about the expected environmental impacts of DLE in the Salton Sea region relies on Chambers Group, Inc. (2021), including air impacts, traffic, and waste generation (Table 1.4). This demonstrates the benefit of sourcing materials from jurisdictions with strict environmental protection laws; the report exists because the California Environmental Quality Act (CEQA) requires companies to prepare detailed EIRs. This is consistent with the principle of evidential equity, which specifies that the burden of proof for demonstrating safety lies with the developer (Colglazier, 2020; Hampton, 1999; Kasperson et al., 1992). At the same time, because EIRs are prepared on behalf of the companies and not by independent researchers, the data may not be transparent or trusted by community stakeholders. Additionally, because permits are issued on a case-by-case basis, environmental impacts such as water consumption and air emissions are evaluated for single facilities rather than the cumulative development.

Dobson et al. (2023) examined water consumption in the context of agriculture and Colorado River water supply. The report also provided an in-depth overview of the waste generation and management from the existing geothermal operations, analyzed air emissions from geothermal facilities, and provided a preliminary assessment of potential DLE emissions, which could be built upon to model potential air quality and associated health impacts. However, since DLE is still under development, the report was generally limited to estimating or speculating about potential impacts. Some information is, therefore, still unavailable or cannot be provided with certainty.

The Comité Civico and Earthworks report (Naimark, 2023) also discusses water use, air emissions, Indigenous rights, waste disposal, and seismicity, with a more explicit discussion of accountability measures needed to support environmental justice. However, it also relied on

Chambers Group, Inc. (2021) and is limited to hypothetical projections about potential impacts or presents information about other lithium extraction and geothermal energy production methods. For example, the discussion of seismicity impacts focuses on enhanced geothermal systems (EGS), a technology not used at the Salton Sea Geothermal Field.

Another challenge is that even if the information is available, EIRs and technical reports are difficult for members of the public to access. Chambers Group, Inc. (2020) is over 1,000 pages long and was prepared mainly with local agencies and policymakers as the intended audience. Meanwhile, the Dobson et al. (2023) report is over 300 pages. Providing information in a dense and highly technical format has been identified as a barrier to procedural justice in other lithium extraction developments (Marchegiani et al., 2020).

DOE added a community engagement mandate that funded a PhD student (me) to work on the Dobson et al. (2023) report. To make the information more accessible, we developed a Frequently Asked Questions document and website, held in-person workshops where people could ask scientists questions directly, and organized briefing meetings with CBOs to share information and get feedback.[3] Overall, we received positive feedback about these efforts, with most participants thanking the team for visiting the area and sharing new information. However, some students and community advocates

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[3] For more information on this process, please see Chapter 12 of Dobson et al. (2023). The FAQ is available in English and Spanish at https://lirric.lbl.gov/faq/.

expressed frustration that presentations focused on the positive aspects of lithium while downplaying potential negative impacts.[4]

Recognition Justice

Recognition justice questions which perspectives are respected and given a voice during decision-making processes (Kennedy et al., 2017; Rodríguez-Labajos & Özkaynak, 2017; Schlosberg, 2007). Kyle Whyte (2011) writes that "recognition justice requires that policies and programs must meet the standard of fairly considering and representing the cultures, values, and situations of all affected parties" (pg. 200) and emphasizes the design of participatory processes as key to improving recognition justice.

Consideration of the rights and worldviews of Indigenous groups is crucial to recognition justice and has been highlighted as an issue for clean energy minerals (Heffron, 2020). According to Whyte (2011), this requires a recognition of what he calls "situational particularities" among tribes, which encompasses "differences in tribes' cultures, experiences with colonization, governing capacities, and political statuses" (pg. 200). Recognizing tribes' environmental heritage and relationship with the "more-than-human" world is also essential.

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[4] One particularly illustrative example is that we presented information about the air emissions in comparison to other regional sources, for example, by comparing H_2S emission from geothermal plants with emissions from the Salton Sea itself. The intention was to contextualize the information; however, a community advocate pointed out that the existing levels of pollution were already unacceptable, and it would be more appropriate to analyze the impacts cumulatively, which was beyond the scope of the pilot study. In this case, I see both sides. In other cases, I believe the criticism is warranted, for instance when researchers start presentations by emphasizing how much more sustainable DLE is compared to other lithium extraction methods.

The Salton Sea has significance for multiple sovereign Tribes, which have distinct histories, economic situations, and perspectives on lithium extraction. The CEC has a tribal liaison and held LVC workshops to gather tribal perspectives, which are summarized in the final report. Additionally, members of the Quechan and Torres-Martinez tribal councils were appointed to the LVC. However, tribal representatives and elders have expressed concern about the development and frustration at the tribal consultation process through op-eds and public comment (e.g., Arrow-weed, 2022). The Quechan Indian Tribe expressed via public comment that their perspective was not accurately reflected in the report, government-to-government consultation has not occurred, and discussions of lithium extraction had focused on benefits without providing sufficient information about the impacts (Quechan Indian Tribe, 2022).

It is also important to recognize other groups who may have difficulty accessing public proceedings. As noted in the introduction, many residents of Imperial County speak Spanish and work in agriculture, meaning they cannot attend public meetings during the day. Special consideration is necessary for farm workers in the region, who are particularly vulnerable to poor air quality and public health issues (Cheney et al., 2022) and face significant barriers to participating in public processes, e.g., due to language barriers, lack of formal education, transportation access, or documentation status (Prado et al., 2017). Farmworkers are also not compensated for water conservation measures the way farm operators are and would, therefore, be significantly impacted by water reallocation. While LVC and other lithium-related public meetings provide Spanish interpretation, they are often still held during the day. Community advocates have also pointed out that many materials are still only available in English (Los Amigos de la Comunidad IV, 2024).

Supporting recognition justice in this development would benefit from further qualitative research, such as interviews and focus groups, to better understand the diverse perspectives of the different tribes and other affected groups and the extent to which they are recognized by current public processes (e.g., London et al., 2020).

Restorative Justice

Environmental justice scholarship has varying interpretations of restorative justice. Heffron's (2020) discussion of restorative justice is relatively straightforward, focusing on managing waste, decommissioning, and restoring extraction sites to their former use. Meanwhile, Forsyth et al. (2021) propose a more profound interpretation of restorative justice, encompassing physical, emotional, and relational healing between perpetrators of harm and victims, as well as between humans and the natural world. They propose the five following characteristics as fundamental attributes of environmental restorative justice (p. 20):

- "Fundamentally oriented towards healing, often of multiple harms, including relational and physical harm to humans/more-than-humans, inclusive of nature;
- Based on requiring direct (not delegated) participation of those with power to take responsibility and make changes, and those who have suffered harm (inclusive of more-than-humans);
- Based on storytelling and dialogue;
- Dependent on identifiable harm, identifiable victims and identifiable individuals, groups or institutions who take responsibility for harm; and

- Geared towards ensuring accountability of those who have created harm to those who have suffered harm, to achieve relational justice."

California regulations require companies to decommission wells and restore sites to their former use as part of their conditional use permit, another benefit of sourcing materials from jurisdictions with environmental protection laws (Imperial County, 2021). However, while decommissioning and end-of-life restoration are important, it is a forward-looking focus aimed at avoiding future harm, which does not consider the historical context of extraction sites or the experiences of people who live near them. In the physical sense, the Lithium Tax partially addresses restorative justice by directing 20% of the revenue from lithium extraction into Salton Sea restoration. However, it does not address more complex dimensions of restorative justice.

Here, things get complicated in pursuing restorative justice in Lithium Valley. As multiple stakeholders have pointed out, the lithium industry is not responsible for the present condition of the Salton Sea region. The place and people living there have experienced decades (centuries, in the case of Native Americans) of cumulative environmental harm due to a variety of factors that span industrial pollution (e.g., agricultural runoff containing pesticides and fertilizer), water transfer agreements, and failed commitments from the State and federal governments to implement restoration plans, all of which are exacerbated by climate change. At the same time, it can also be argued that they benefit from situations of injustice such as dispossession of Native land and a receding Salton Sea that exposes new lithium deposits, and are therefore a legitimate subject of reparations efforts. And in any case, any incoming industry (or researcher, for that matter) is perceived through the lens of peoples' previous experiences and must therefore contend with the legacy of those who came before them.

A restorative justice agenda for the region overall is outside the scope of this chapter. However, it is helpful to conceptualize the existing social and environmental crises as a “wicked problem” requiring complex solutions (Huang & London, 2013). Projects seeking to respond to wicked problems have found that community partnerships, investing in skilled facilitation, and budgeting sufficient time for problem identification and building trust are critical to achieving successful outcomes (Huang & London, 2016).

Discussion and Conclusion

Lithium Valley is an ongoing development; it has progressed even as I have been writing the chapter, and there are certainly initiatives, events, and perspectives that are not captured here.[5] Meanwhile, the companies are still working to validate DLE’s economic and technical viability at a commercial scale. Therefore, what is captured in this dissertation should be considered a snapshot. Nonetheless, this snapshot presents important lessons for other transition mineral developments (Table 1.5).

Regarding distributive justice, DLE has the potential to benefit the local community by generating employment and providing a source of revenue that could help address existing challenges in the region, including public health and environmental restoration. The industry would also require transportation and telecommunications infrastructure upgrades that are needed in the area and could improve internet and mobility access. Meanwhile, the potential environmental burdens include

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[5] For example, the California Energy Commission recently started a new series of public workshops to define the Lithium Valley vision, the County is in the process of updating their website, and reports from the CBOs tasked with outreach will be available in the upcoming months.

increased traffic and solid waste generation. Another critical environmental issue is water consumption. While DLE is not expected to interact with groundwater, it represents a new source of demand for Colorado River water, which could create tension with competing uses if current water scarcity issues continue.

On the positive side, there are several novel initiatives related to community benefits, outreach, and workforce development that, if successful, could be applied to other developments. For example, the Lithium Tax (SB 125) ensures that some of the economic benefits will accrue to frontline communities in Imperial through tax revenue, which ties directly into distributive justice. The provision that 20% of the tax be reinvested in Salton Sea restoration connects to restorative justice, as it responds to a longstanding environmental hazard that has burdened local communities for decades.

While workforce development initiatives and the lithium tax indicate real potential for community benefits, they do not guarantee it. CBOs, non-profits, and labor unions have advocated for companies to sign enforceable community benefits agreements (CBAs) to ensure the promises made during development accrue to local communities (Benner et al., 2024; Figurasin, 2024). Research could help validate community benefits by evaluating impacts such as local employment, housing affordability, and infrastructure investment as the industry develops (e.g., Liu & Agusdinata, 2020). Socioeconomic impacts can also be accounted for using social life cycle assessment, which evaluates the impact of a product or system across different stakeholder and impact categories (Fortier et al., 2019; UNEP, 2020). This enables structured comparison between production pathways, which could incentivize companies to adopt practices that have higher costs but create more benefits for the surrounding community, e.g., paying their employees a living wage.

Table 1.5: Lessons from the Lithium Valley Development.

	Positive examples	**Challenges and limitations**	**Recommendations**
Recognition justice	• Information provided in multiple languages and at convenient times. • Representatives from CBOs and Tribes appointed to the LVC.	• Community members have diverse and potentially conflicting perspectives. • Most engagement follows typical public meeting format and may be dense or inaccessible. • Criticisms re: inadequate tribal consultation.	• Research, programs to understand diverse perspectives about lithium extraction among Tribes and other stakeholders, identify effective engagement methods.
Distributive justice	• Lithium Tax directs revenue to frontline communities. • Workforce development initiatives. • Environmental protection laws and permitting process. • Programmatic EIR, including health impact assessment.	• Accessibility of training opportunities for residents who live farther from opportunities or face other barriers to participating. • Financial viability of geothermal DLE in the global market. • Complex dynamics between environmental and socioeconomic factors, e.g., water allocations.	• Accountability for community benefits (e.g., through CBA) and transparency about how revenue is invested. • Plan for affordable housing. • Transparent monitoring and reporting of environmental impacts, including water use, air quality, waste disposal, and seismicity. • Evaluate cumulative impacts.
Procedural justice	• LVC: regular public meetings, docket with information, public comment opportunities. • SB 125 funding for CBO-led outreach. • Information available from EIRs, data reported to state agencies. • Community engagement included in government-funded research.	• Incomplete information due to novelty of technology. • Information is still highly technical and difficult to access. • Criticisms re: inadequate tribal consultation. • Adapting state procedures to be more flexible and dialogue based.	• Ongoing communication between scientists, industry, government, and community stakeholders to share information as it becomes available. • Centralized platform (i.e. website) where people can access information. • Dedicate more resources, including funding and personnel, to community engagement. • Improve tribal consultation, including providing technical assistance.
Restorative justice	• Lithium Tax requires investment into Salton Sea restoration. • Conditional use permits include requirements for system closure and site restoration.	• History of environmental harm and marginalization extends well beyond the lithium and geothermal industries. • Perceived urgency of securing lithium supply and competing with global producers conflicts with the time necessary for more meaningful dialogue and engagement.	• Ongoing facilitated dialogue to rebuild trust between communities, state, and industry.

There are also useful lessons related to procedural justice. By establishing the Lithium Valley Commission, the State ensured that transparent conversations about the resource took place before it was developed, with representation from community advocates and Tribal nations at the table (or on the Zoom webinar, as it were). The LVC also provided a robust source of data about community perspectives on lithium extraction through public comments recorded during meetings or submitted to the public comment docket. Later, SB 125 provided funding for CBOs to do outreach, which is a positive step in terms of procedural justice, as it facilitates broader public input into the decision-making process.

At the same time, the extent to which community feedback can influence the development is unclear. According to Holland (2017), the ability to voice concerns is not sufficient to realize procedural justice unless the populations involved have the political power to shape decisions and processes. While the State and County have made a concerted effort to broaden public participation, the engagement methods are generally limited to formats that limit dialogue. Additionally, the difference between the content LVC and community-focused meetings indicates that while voices from marginalized communities were included, they were not necessarily centered.

Public discussions of Lithium Valley tend to emphasize the benefits and sustainability of the development rather than the potential impact (e.g., the importance of lithium in the clean energy transition, the relative sustainability of DLE compared to other extraction methods, and the potential to benefit the community through jobs). A similar phenomenon has been observed in other lithium extraction developments; for example, in Argentina, the lack of clear information about the potential impacts was identified as a barrier to Free, Prior, and Informed Consent for Indigenous communities (Marchegiani et al., 2020). In both Argentina and Lithium Valley, this has left community members frustrated that their questions about the potential impacts are not answered transparently.

Based on available literature about DLE and geothermal, I did not find evidence that this positive framing is intentionally misleading or inaccurate. However, available reports do not address cumulative impacts and are limited to modeling *potential* outcomes with incomplete information due to the proprietary technology (e.g., the type of sorbents that will be used). This reveals a practical challenge in the implementation of procedural justice, one that is likely to surface in other developments. Many novel technologies are expected to be more sustainable than status-quo production methods; however, if they are not commercially available, there is no measured data on their environmental impact and performance, which makes it difficult, if not impossible, to address community concerns. Therefore, monitoring is necessary to validate sustainability as the industry develops.

Finally, environmental justice scholarship has demonstrated that building trust and achieving just outcomes requires participatory, dialogue-based processes with skilled facilitation and recognition of all viewpoints (e.g., Huang & London, 2016; Hampton, 1999). Rebuilding trust is particularly important in the Salton Sea region, where communities have seen researchers study the area for decades but have yet to see a meaningful improvement in their quality of life. Furthermore, communities' history with the state and previous industries makes many skeptical that the promised benefits will be realized. Stakeholders in privileged positions, i.e., policymakers, researchers, or industry, should, therefore, expect to invest a good deal more time and resources into community engagement than they are currently allocating.[6]

While the Salton Sea is a uniquely challenging situation, many other critical mineral resources are also in areas with complex histories of marginalization and mistrust. Thus, facilitated dialogue, participatory research, and accountability for harm-- past, present, or future—should also be prioritized to achieve just outcomes and build trust in other developments. At the same time, the fact that clean energy minerals are urgently needed for climate change mitigation adds pressure that makes it difficult to conduct more participatory decision-making processes.

Limitations and suggestions for future research.

Many of the insights and recommendations identified here are informed by content analysis of state-led public meetings and community-focused meetings. The contribution of this method is systematically codifying the perspectives of stakeholders who may not otherwise be represented in academic literature and are thus excluded from the scientific process by not being citable. The advantages of using content analysis in this capacity are twofold; first, compared to surveys or interviews, it does not place an additional burden of time or effort on stakeholders who are already voicing their opinions in other forums. Second, it may be readily utilized by scientists in traditionally quantitative disciplines who seek to connect their research with marginalized communities.

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[6] While the CEC While the CEC invested $6 million to support BHER's DLE demonstration facility, the LVC had no dedicated community engagement budget (California Energy Commission, 2020).

One limitation is that publicly accessible meetings may not be available in other developments. Another limitation is that the views expressed in community meetings may represent the most outspoken residents rather than the majority of community members. Additionally, while it is less burdensome, the listening-based approach does not actively engage community members and is less empowering than more participatory research methods.

There are many opportunities for future research to build on the analysis presented here. One valuable area of study would be analyzing the State-led community engagement and tribal consultation process in greater detail to identify barriers to participation, particularly for the most marginalized groups such as farmworkers or Indigenous communities, and evaluate the ability of community members to shape the outcome of a proposed development, including whether all parties agree that free, prior, and informed consent is upheld during the planning and development process. It would be valuable to analyze CEQA and the capacity of the law to uphold procedural and distributive justice while enabling the clean energy transition to move forward.

This chapter adds to a growing body of literature studying critical minerals in the context of energy justice. Most articles in this subject area fall into two camps: sustainability analyses that quantify the environmental impact of clean energy technologies focusing on greenhouse gas emissions (e.g., life cycle assessments), and social science research analyzing supply chains using the framework of green extractivism. The latter takes a critical approach, analyzing how clean energy technologies and supply chains reinforce unjust systems of power and exploitation. In this chapter, I endeavored to bring the two closer together. This work makes a valuable contribution to quantitative sustainability research by elevating the priorities of local community members, whose perspectives are often overlooked in science, and connecting environmental and socioeconomic impacts with more complex layers of history and social context. On the other side, the contribution of this chapter in the context of green extractivism literature is that I examine a state-led effort to proactively develop a lithium resource in a way that benefits the local community. In doing so, I hope to generate productive insights to inform future developments, because, realistically, all possible paths towards decarbonizing involve some level of mineral extraction. While I focus on lithium and DLE, balancing global and local impacts will be relevant to many other essential clean energy technologies, including wind, solar, and hydropower.

Chapter 2: The global benefits and local impacts of producing lithium-ion batteries in a geothermal manufacturing hub

Abstract

This chapter analyzes a hypothetical battery manufacturing hub located in Imperial, California, that produces lithium-ion battery cells using geothermal energy and locally sourced lithium from geothermal brines. The hub activities include lithium hydroxide (LiOH) production, precursor and cathode active material synthesis, and cell assembly. The life cycle impacts are modeled using data from ecoinvent and compared to alternative pathways with varying freight transportation distances and energy inputs. In addition, I analyze the potential production capacity and the associated cumulative water use, energy demand, and waste generation in the context of local resource constraints. I find that producing a cell in a hypothetical geothermal hub reduces greenhouse gas emissions by approximately 36% compared to a battery produced using market lithium and conventional energy inputs in the Southeast United States. The primary driver of reduced emissions is the use of geothermal energy for process heat and energy, followed by the lower-carbon LiOH source. Avoiding freight transportation of LiOH has a limited impact on the overall carbon footprint. The current water allocation could support approximately 106 gigawatt-hours (GWh) of cathode active material (CAM) and cell production per year, which would use roughly 83% of the announced lithium production capacity (34 of 40 kilotons per year). This would require developing an additional 715 megawatts (MW) of geothermal production capacity, or around fifteen 50 MW power plants. A hub with this level of production capacity would produce an estimated 636 kilotons of waste per year, of which approximately 20% is expected to be classified as hazardous waste and require specialized treatment. These results suggest that collocating battery manufacturing with a renewable resource has a greater impact on the life cycle greenhouse gas emissions than collocating near a lithium resource, although there may be economic benefits associated with collocating near mineral extraction, particularly in terms of job creation. The Salton Sea region could therefore be an attractive location for manufacturing even without lithium extraction, particularly if new geothermal facilities are designed to produce process heat in addition to electricity. However, new developments should be considered within a water budget based on constraints, competing uses, and the informed participation of local communities.

Introduction

Electric vehicle (EV) sales are rising worldwide, driven by climate policies and market innovations. As widespread adoption becomes a reality, major EV markets have started to focus on clean energy supply chains, particularly those that underpin lithium-ion batteries (LIBs). Securing access to "critical minerals" is now a key priority for the United States and for governments across the globe, including Europe, China, Canada, Australia, Japan, Korea, and India. These regions, among others, have defined their own lists of critical minerals and are pursuing strategies to onshore critical minerals production and establish trading partnerships (Andersson, 2020; European Commission, 2019; Government of Canada, 2023; Infrastructure Investment and Jobs Act, 2021; Madeleine King, 2023; Parliament of India, 2023; The White House, 2021). Similarly, there has been heightened support for domestic manufacturing and recycling in these areas. In the Global North, these initiatives emphasize sustainability as part of their motivation for pursuing domestic extraction, leading to a novel phenomenon termed the "Sustainability-Security Nexus" (Riofrancos, 2022).

In the United States, vehicle electrification and manufacturing have been high priorities for the Biden Administration, resulting in several influential reports and policies related to EV and LIB supply chains. The White House 100-Day Supply Chain Review assessed four key products, including large-capacity batteries, providing an overview of the production landscape and supply risks (The White House, 2021). Following the publication of the Supply Chain Report, several landmark pieces of legislation were introduced to support the uptake of EVs and catalyze investment in domestic LIB and component manufacturing, most notably the Infrastructure Investment and Jobs Act, commonly known as the Bipartisan Infrastructure Law (BIL), and the Inflation Reduction Act (IRA). The Biden

Administration also established an Office of Supply Chains and Manufacturing within the Department of Energy (DOE).

The BIL appropriated over $62 million to new and existing DOE programs to support domestic critical minerals supply chains, battery processing and manufacturing, EV battery recycling and second-life applications, and critical minerals mining and recycling research (Infrastructure Investment and Jobs Act, 2021). The funding is distributed via formula funds to states and competitively awarded grants. Meanwhile, the IRA established regional and domestic mineral sourcing requirements, where manufacturers must source a minimum percentage of certain materials domestically or from a specified list of countries in order to be eligible for EV tax incentives (Inflation Reduction Act of 2022, 2022) Less than two years after the passage of the IRA, an estimated $85 billion of investment has been announced in North America, supporting 96 announced projects (Turner, 2024).

A novel aspect of recent federal policy is a deliberate focus on environmental justice and local communities. For example, the Biden Administration's Justice40 Initiative directs "40 percent of the overall benefits" of certain clean energy investments to flow to disadvantaged communities (*Exec. Order 14008*, 2021). The interim guidance gives examples of benefits, which include creating good-quality jobs or decreasing energy burden, as well as how these benefits could be calculated and reported (Young et al., 2021). Applicants for BIL or IRA funding were also required to submit Community Benefits Plans as part of their proposal, which were scored at 20% of their technical merit review (U.S. Department of Energy, n.d.).

There are two overarching goals at the heart of these initiatives: (1) reducing carbon emissions from transportation, and (2) upholding environmental justice in the clean energy transition, including for communities near sites of extraction and production ("frontline communities"). With these goals in mind, this chapter analyzes the proposed development of a lithium resource found in geothermal brines near the Salton Sea in Imperial County, California, focusing on the environmental implications. Stakeholders at the State and local level envision these geothermal brines providing a sustainable source of lithium that is eventually used onsite to manufacture batteries locally, transforming the region into "Lithium Valley" (Paz et al., 2022). Lithium Valley could offer multiple avenues to improve the sustainability of LIB production, namely, a low-impact source of lithium and a manufacturing hub powered by clean energy. Supporters of Lithium Valley also point to the environmental advantages of collocating multiple steps of the value chain to reduce emissions from freight. However, these benefits have not been quantified.

Quantifying the benefits of alternative battery production pathways is important to enable comparison with the business-as-usual supply chain, which can inform more effective decarbonization policy and create a competitive advantage for companies that adopt sustainable practices such as utilizing renewable energy. At the same time, the local environmental impacts of concentrating multiple production steps have not been investigated, which is necessary so local stakeholders can make informed decisions about whether they support the development. For example, while society's attention is focused on lithium extraction at the moment, the water demand of manufacturing is also an important consideration and has been raised as an issue in other areas that support production hubs, including the Tahoe Reno Industrial Complex that hosts the Panasonic and Tesla Gigafactory in Nevada (Chereb, 2014).

Imperial Valley is a water-scarce region that relies on the Colorado River, and water use has been among the most prevalent issues raised in public meetings about the development (Slattery et al., 2023). The existing water supply is expected to be sufficient for announced lithium and geothermal projects (Dobson et al., 2023); however, the cumulative water consumption of lithium extraction, energy production, and value-added manufacturing has not been estimated. Furthermore, Imperial's future water allocation is not guaranteed, as drought and dwindling supply have prompted ongoing negotiations among the various stakeholders and States that rely on water from the Colorado River Basin (Stern et al., 2024). Waste and air emissions are also important environmental concerns for the communities surrounding Lithium Valley, who are already burdened by poor air quality and pesticide exposure (*CalEnviroScreen 4.0*, 2021; Johnston et al., 2019; Mendoza et al., 2010; Naimark, 2023). This chapter, therefore, estimates the GHG emissions to identify lower-carbon manufacturing pathways while also analyzing the local impacts in terms of cumulative water consumption and waste generation.

The rest of this chapter is structured as follows. First, I review the literature about direct lithium extraction (DLE) from geothermal brines and regionalized battery production. I then conduct a cradle-to-gate life cycle assessment (LCA) of an nickel-manganese-cobalt (NMC) 811 battery cell produced from a hypothetical geothermal battery hub in Imperial, California, compared to alternative production scenarios. The goal of the LCA is to quantify the relative environmental benefits of using low-carbon energy for manufacturing, reducing freight distance, and producing batteries with a lower-impact source of lithium. The LCA is complemented by an assessment of the potential local impacts relating to water availability and waste generation, where we determine a feasible level of lithium, cathode, and cell production given local resource constraints. Finally, I discuss policy implications, identify limitations of the study, and recommend areas for further research.

Literature Review

Direct Lithium Extraction from Geothermal Brines

The Salton Sea geothermal brine is in a subsurface reservoir approximately two kilometers below the Earth's surface (McKibben et al., 1987). It contains a variety of minerals, including zinc, magnesium, calcium, potassium, and lithium (McKibben et al., 2020). At present, the brine is brought to the surface for geothermal energy production, and there are 11 power plants operating in the region with a combined power output of approximately 400 MW (Dobson et al., 2023; Paz et al., 2022). Energy is produced using a flash process, where the high-temperature brine is passed through a series of separators and flash tanks that separate steam from brine. The steam then powers a turbine to generate electricity. Meanwhile, the remaining brine is clarified by precipitating a solid iron-rich silicate, then reinjected into the reservoir through injection wells. At present, lithium and most other minerals remain in solution and are reinjected. However, three companies are developing technology to recover lithium using direct lithium extraction (DLE) (Dobson et al., 2023; Stringfellow & Dobson, 2021; Vera et al., 2023).

Peer-reviewed research about DLE from geothermal brines is limited, as the technology has not yet been deployed at a commercial scale. However, several studies provide helpful insight into the feasibility of the technology and its potential impacts. These can be categorized into (a) technical papers reviewing or assessing the performance of DLE processes; (b) papers evaluating the feasibility of geothermal DLE, particularly from Salton Sea geothermal brines; or (c) papers about the environmental impact of DLE.

Regarding the technical aspects of DLE, Stringfellow & Dobson (2021) reviewed different processes for DLE, concluding that molecular sieve ion-exchange sorbents were the most advanced method. The potential sorbent materials that could be used include aluminum hydroxide, manganese oxide, and titanium oxide. Pretreatment is typically required to remove unwanted minerals that might otherwise interfere with the extraction process, such as sodium, potassium, calcium, and magnesium, although the level of pretreatment depends on the performance of the sorbent in terms of how well it recovers lithium vs. other elements. Paranthaman et al. (2017) demonstrated the lab-scale performance of a lithium double hydroxide (LDH) sorbent, reporting an extraction efficiency of 91%. The process uses a three-step column extraction cycle: (1) loading sorbent with lithium chloride from brine; (2) intermediate washing to remove unwanted ions; and (3) final washing to unload lithium chloride ions. Torres et al. (2020) demonstrated a lithium recovery process using membrane electrolysis with brine from Salar del Hombre Muerto in Argentina, following pretreatment processes from Díaz Nieto et al. (2019, 2020), which also use membrane electrolysis. Ventura et al. (2020) developed a sorbent with a lot of complicated words, including “azobisisobutyronitrile.”

Regarding feasibility, Neupane & Wendt (2017) compiled a database of geothermal brine compositions in the US, looking at the occurrence of lithium along with various other minerals, including silver, gold, copper, manganese, and rare earth elements. They find that geothermal brines in the Salton Trough are among the most attractive for mineral recovery due to their high levels of total dissolved solids, with silver, copper, lithium, manganese, lead, and zinc all having potential recovery value. Meanwhile, Toba et al. (2021) use a Systems Dynamics model to investigate the viability of recovering lithium from geothermal brine in Imperial, California, and Beaver, Utah, using an LDH-based sorbent. In their model, the quantity of lithium produced is partially determined by the market price of lithium. Their results suggest that US geothermal Li extraction is economically viable and could represent 4-5% of the total global supply from 2020-2030. Finally, Warren (2021) performed a technoeconomic analysis of DLE from geothermal brines. They reported expected production costs of around $4,000/metric ton of lithium carbonate equivalent (LCE) and suggest that DLE should be economically feasible with estimated prices over $11,000/mt LCE (Warren, 2021).

Research about the environmental impacts of DLE is limited. Flexer et al. (2018) propose DLE as a more sustainable alternative to brine evaporation, as it is a faster process and has a much smaller physical footprint (Flexer et al., 2018). Vera et al. (2023) provide the most comprehensive overview of the potential environmental impacts of DLE, highlighting questions about freshwater consumption, energy use, and waste generation. According to their review, estimates of freshwater requirements vary widely between available studies, from <1 to over 500 m^3 per mt of $LiCO_3$ produced. Furthermore, energy requirements are rarely provided in published studies, and if they are, it is only for certain aspects of the process. Pumping and pre-processing are often excluded, making it difficult to compare to other production methods. Finally, they highlight the importance of managing waste from DLE, which is estimated to be 115 tonnes per tonne of LCE.

The only detailed life cycle assessment (LCA) of DLE from geothermal brines is Huang et al. (2021). They estimate the impact of producing $LiCO_3$ and LiOH from Salton Sea geothermal brines, using the LDH sorbent from Paranthaman et al. (2017) to concentrate lithium chloride. They model two scenarios for the energy input: one where grid electricity is used, and another where all electricity is from geothermal. They found that compared to conventional production methods, DLE had a lower impact across all categories, with a 33-41% reduction in global warming potential and a 72-86% reduction in respiratory effects compared to lithium produced via brine evaporation. The largest drivers for all impact categories were sodium carbonate ("soda ash") usage and LDH sorbent synthesis, as well as hydrated lime consumption for LiOH. They also note that the environmental impacts are sensitive to uncertainties in the conversion rate of $Li2CO_3$ and LiOH.

Regionalized Battery LCA

Researchers at Argonne National Laboratory have evaluated the impact of regionally specific supply chains, modeling NMC 111 production in the US, China, Japan, South Korea, and Europe (Kelly et al., 2019). They find significant regional differences in life cycle carbon dioxide equivalent (CO_2e) emissions, with batteries produced in Europe having the lowest CO_2e emissions due to the lower-carbon electricity grid. Kelly et al. (2019) also account for regional variability in nickel, aluminum, and cobalt sulfate refining, highlighting significant differences in the local pollutant emissions of nickel refining pathways. Ultimately, they recommend maximizing the use of renewable electricity in manufacturing and sourcing materials from locations with strong environmental regulations so that local pollutant emissions are mitigated.

Hung et al. (2021) provide a more granular analysis for Europe, analyzing the carbon footprint of battery EV production across EU member states based on country-specific electricity mixes. They find that while the overall average EU grid mix has a low carbon intensity compared to other regions, there is heterogeneity across member states. Some countries represent an increase in carbon intensity for battery manufacturing compared to business-as-usual production in Asia. This highlights the importance of location-specific analysis of GHG emissions, rather than relying on broader regional averages.

I did not identify any existing studies that investigate the impact or benefit of collocating multiple production phases. A key environmental benefit of collocating production is reduced shipping, and life cycle assessments about LIBs rarely focus on the impact of the transportation phase (Slattery et al., 2021). However, one study that provides insight is Ciez and Whitacre (2019), who included the transportation of input materials and collection of spent batteries in their analysis of battery recycling processes. The authors estimated that the transportation of materials contributed 0.33 kg CO_2e per battery, which represented 3.5-4% of the overall life cycle emissions assuming that most input materials were produced in the US. This could represent an upper bound of the potential to reduce emissions through collocation.

This paper builds on the studies referenced above by estimating the value of collocating production near a mineral resource, which has not been investigated to date, and analyzing the cumulative impact of a manufacturing hub in the context of local environmental constraints. I also evaluate geothermal energy as a potential source of both process heat and electricity for manufacturing;

other studies only consider renewable or low-carbon energy for process electricity, not heat, and none include geothermal.

Methods

LCA is a systematic method for quantifying the environmental impacts of a process or technology throughout its life cycle phases (ISO, 2006). While the LCA method has been codified for more than two decades, individual LCAs vary due to practitioner choices and real-world differences in product life cycles. For example, some studies evaluate the entire life cycle, encompassing raw material extraction and refining, production, transportation, use, and end-of-life. This is often referred to as a "cradle-to-grave" study. Others may just focus on production, which is referred to as "cradle-to-gate." The activities that are included or excluded are defined by the study's system boundary and are selected based on the study's intended goal and application.

The goals of this LCA are to quantify the impact of LIB cells produced in a geothermal manufacturing hub compared to more common supply chain pathways and to determine the relative importance of potential sustainability drivers: using a cleaner source of lithium (i.e., DLE powered by geothermal electricity), reducing freight transportation, and using a low-carbon energy source for process heat and energy. This LCA is a "cradle-to-gate" study, with system boundaries that include material extraction and refining, component production, and cell assembly. The functional unit of this study is one kg of nickel-manganese-cobalt (NMC 811) cells. Figure 2.1 illustrates the system boundary of this LCA.

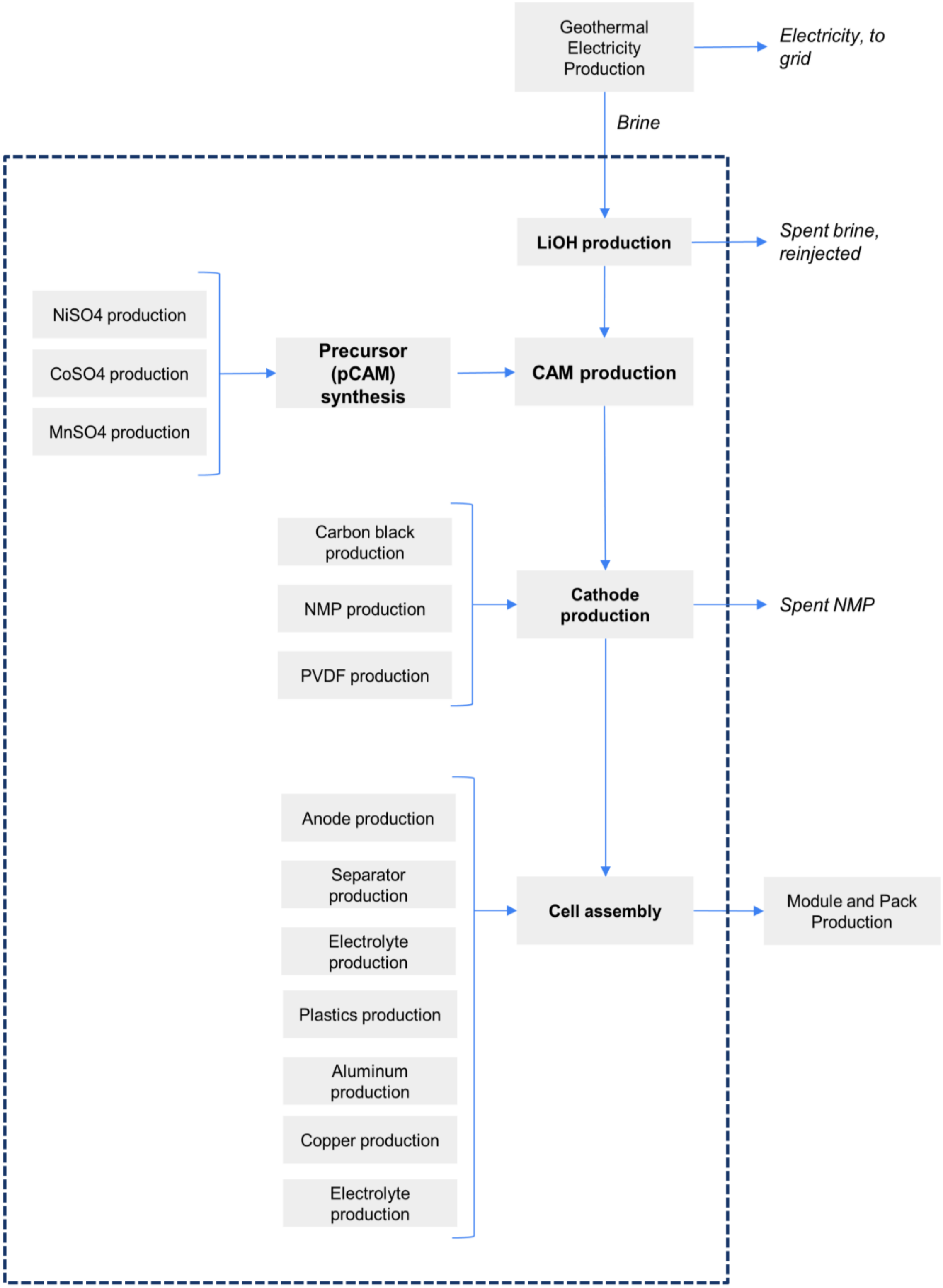


Figure 2.1: LCA System Boundary. The process steps written in bold font are modeled with site-specific parameters. All other processes use unmodified ecoinvent datasets.

I model five scenarios to examine the relative influence of different production choices along the lithium-to-cell pathway: lithium extraction, precursor cathode active material (pCAM) synthesis, cathode active material (CAM) production, and cell assembly (Table 1). According to industry stakeholders, CAM is easier to transport than pCAM or the final cathode product; pCAM is anhydrous and highly sensitive to moisture in its environment, and the cathodes are fragile and easily damaged in transport (Sizemore, personal communication, 2023). I therefore assume that in all scenarios, pCAM and CAM are produced at the same location, and cathode production takes place in the same facility as cell assembly. A description of each scenario is provided below:

- **Geothermal (GT) DLE:** Lithium is extracted using DLE from geothermal brine. Lithium refining and manufacturing are collocated and powered directly by geothermal energy.
- **WECC DLE:** Lithium from geothermal brines is used to produce batteries in Imperial. Manufacturing uses conventional energy inputs (electricity from the Western Electricity Coordinating Council (WECC) and natural gas for heat).
- **GT Market Lithium:** Manufacturing takes place in Imperial using geothermal for electricity and heat and market lithium hydroxide imported from Chile and Australia.
- **SERC DLE:** Manufacturing takes place in Kentucky using lithium from geothermal brines. This scenario is based on the planned BlueOval development, a joint venture between SK Innovations and Ford Motor Company, assuming BlueOval procures lithium from Imperial.
- **SERC Market Lithium:** Manufacturing takes place in Kentucky using market lithium hydroxide imported from Chile and Australia.

Table 2.1: Scenario Assumptions

Scenario	**Li extraction**	**CAM and cell production**	**Transportation***
GT, DLE	Imperial, CA DLE	Imperial, CA ● Heat and electricity: geothermal	● 1 km by truck within Niland, CA
WECC, DLE	Imperial, CA DLE	Imperial, CA ● Heat: natural gas ● Electricity from WECC production mix	● 1km by truck within Niland, CA
GT, Market Li	50% from Atacama, Chile (brine evaporation) 50% from Kemerton, Australia (hardrock mining from spodumene)	Imperial, CA ● Heat and electricity from geothermal	From Chile: ● 40 km by truck from production site to Port of Antofagasta, Chile ● 8204 km in container ship from Antofagasta to Port of Los Angeles ● 106 km by rail to Inland Empire intermodal terminal ● 222 km by truck to Niland From Australia: ● Truck 154 km from Kemerton to Fremantle Harbour ● Ocean tanker 4050 km from Fremantle Harbour to Sydney ● Ocean tanker 12058.37 km from Sydney to Port of Los Angeles ● 106 km by rail to Inland Empire intermodal terminal ● 222 km by truck to Niland
SERC, DLE	Niland, CA DLE	Glendale, Kentucky ● Heat from natural gas ● Electricity from SERC production mix	● 400 km by truck to Phoenix, AZ ● 2777 km by rail to Louisville Intermodal Terminal, KY ● 72 km by truck to Glendale, KY
SERC, Market Li	50% from Atacama, Chile (brine evaporation) 50% from Kemerton, Australia (hardrock mining from spodumene)	Glendale, Kentucky ● Heat from natural gas ● Electricity from SERC production mix	● Same as GT, Market Li scenario

* Refers to transportation of lithium hydroxide only, which was modeled distinctly for each scenario. In all scenarios, non-lithium inputs (e.g. nickel sulfate, aluminum hydroxide) are modeled using the "market activity" datasets from ecoinvent, which include embedded energy and transportation assumptions based on global and regional averages (ecoinvent, 2020). This means the impact of transportation is included for other materials but not modeled separately, and does not vary by scenario. Assumptions for lithium from Chile are based on Kelly et al. (2021). Assumptions for lithium from Australia are based on Albemarle (2018).Transportation distances between ports are taken from National Geospatial Intelligence Agency (2001).

LCA is an effective tool for identifying total supply chain impacts across a product's life cycle, particularly energy use and greenhouse gas emissions. However, the location of impacts is not spatially resolved, meaning it is not the most suitable method for analyzing local impacts (Breetz, 2017). Furthermore, from a local perspective, it is more useful to estimate the cumulative impact of production processes occurring at a site or region, rather than the impact per kg of cell produced. Considering these limitations, I focus on climate change impacts when interpreting LCA results, but complement the LCA with a localized analysis of the potential water consumption and waste generation that would be associated with a battery manufacturing hub.

Life Cycle Inventories

A life cycle inventory (LCI) quantifies the environmental inputs and outputs required to produce a specified product or complete a process. LCIs can be obtained by gathering site-specific facility data, performing lab-scale experiments, or using existing datasets, typically referred to as reference LCIs. Here, I use reference LCIs, mainly taken from the ecoinvent database (ecoinvent, 2020). Ecoinvent contains information related to the processes, materials, and energy flows for a wide variety of industrial sectors and is regularly updated to reflect technological advancements and different regions of production (Moreno-Ruiz et al., 2023). The datasets are based on unit system operations (u-so), which quantify the direct inputs and outputs for specific products. Below, the key production steps and materials for battery manufacturing are described, along with the methods used to develop their LCIs.

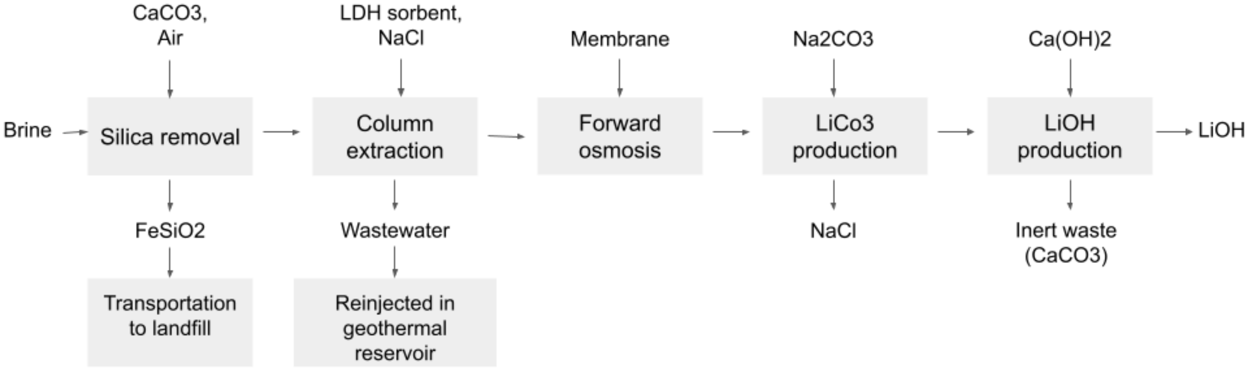


Figure 2.2: Flow diagram for LiOH production from geothermal brine, including pretreatment, LiCl concentration, $LiCO_3$ production, and LiOH production.

LiOH production. While specific processes and technologies vary, DLE generally starts with a pretreatment phase to clarify the brine. This involves precipitating silica and separating out calcium and magnesium, which would otherwise be likely to interfere with lithium recovery (Díaz Nieto et al., 2019). Pretreatment is followed by a lithium extraction and recovery process to concentrate lithium from the brine, typically as lithium chloride. Finally, the lithium chloride undergoes post-extraction processing to remove impurities and convert it to a battery-grade product, typically lithium carbonate ($Li2CO_3$) or lithium hydroxide monohydrate (LiOH).

In the GT/DLE, WECC/DLE, and SERC/DLE scenarios, I assume lithium is recovered using the adsorption-based DLE process described by Huang et al. who also use ecoinvent datasets. The scope of their LCI includes sorbent synthesis, column extraction, forward osmosis, $LiCO_3$ production from concentrated LiCl solution, and LiOH synthesis from $LiCO_3$ (Huang et al., 2021). In this study, I recreate the LCIs for these steps as closely as possible, with minor modifications due to data accessibility. Additionally, Huang et al. (2021) model two scenarios, one where all energy is produced with grid electricity, and one where all energy is supplied by geothermal. Here, I assume that the sorbent is produced offsite in California, meaning it uses the WECC grid electricity mix, while the DLE process uses geothermal energy. Energy for pumping is not included, as the Salton Sea geothermal brines are at such a high temperature and pressure that they naturally rise to the surface once a production well is drilled.

Huang et al. (2021) exclude pretreatment from the scope of analysis, though pretreatment is expected to generate a substantial amount of solid waste. Waste generated during the direct lithium extraction process is not commonly included in environmental assessments of lithium or battery production; however, it was identified as an important area of consideration for DLE (Vera et al. 2023) and is consistently raised as a concern by local community members and organizations (Slattery et al. 2023; Naimark 2023). I therefore add a silica removal pretreatment process and the resulting waste to the scope of this LCA, based on publicly available patents and environmental impact reports for EnergySource Minerals (ESM) (Chambers Group, Inc., 2021; Featherstone et al., 2020; Marston & Garska, 2019). These calculations are described in Appendix (A2.2). Energy for pumping is not included, as the Salton Sea geothermal brines are at such a high temperature and pressure that they naturally rise to the surface once a production well is drilled.

I compare my results to the conventional LiOH dataset in ecoinvent ("Ecoinvent Market"), which aggregates $LiCO_3$ from brine and spodumene ore (ecoQuery, n.d.-b). However, brine evaporation and hard-rock mining from spodumene have substantially different impacts. To compare the impact of LiOH production from DLE with distinct lithium sources, I created two additional datasets modeling LiOH production. These use the corresponding ecoinvent $LiCO_3$ datasets for brine and spodumene as inputs, then model the LiOH synthesis process from Huang et al. (2021).

Precursor and cathode active material (pCAM and CAM). One of the most common methods of producing pCAM is through co-precipitation, where metal sulfates (cobalt sulfate, manganese sulfate, and nickel sulfate) are reacted with sodium carbonate or sodium hydroxide (Ahmed et al., 2017; Entwistle et al., 2022; Malik et al., 2022). This reaction occurs in a continuous-stirred tank reactor, which uses water and heat from steam. The solid precipitate is washed to separate dissolved sulfates and carbonates from the precipitates, resulting in additional water use, then dried and milled to make NMC hydroxide powder, using additional heat and electricity. Additionally, ammonia is emitted during precursor synthesis at a rate of 0.0058 kg per kg pCAM and must be removed from the wastewater in an ammonia stripping tower (Dai et al., 2018).

To make CAM, pCAM is mixed with LiOH ("lithiated"), then calcined and sintered in an electric kiln at temperatures up to 1000 degrees Celsius to produce Li-NMC 811 oxide (Ahmed et al., 2017; Dai et al., 2018). Calcination and sintering are industrial thermal treatment processes where a powder is compacted and heated to a temperature high enough that the particles bond and form a solid material. This requires a substantial amount of energy. Several studies have reported that the sintering and calcination process is by far the largest driver of energy consumption during the CAM manufacturing process (Ahmed et al., 2017; Dai et al., 2018; Dunn et al., 2012).

Here, the LCIs for pCAM and CAM production (Table A1b and A1c) recreate the u-so from the ecoinvent database, which includes heat, cobalt sulfate, nickel sulfate, manganese sulfate, sodium hydroxide, cooling water, and factory construction. I used the ecoinvent market inventory datasets for inputs (e.g., nickel sulfate) so that my analysis would reflect the transportation of these materials. Ecoinvent market datasets represent "the consumption mix of a product in a given geography…they also account for transport to the consumer and for the losses during that process, when relevant" (ecoinvent n.d.)

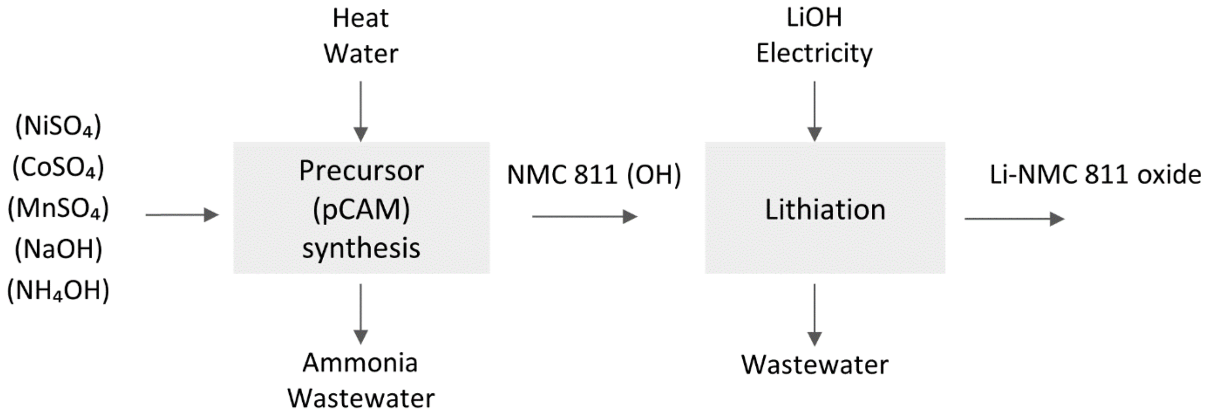


Figure 2.3: Flow diagram for NMC 811 cathode active material production, including precursor synthesis and lithiation.

Cell assembly. Before the cell is assembled, CAM is coated on an aluminum current collector, then fed into a slitting machine and cut to size to make the cathode (Ellingsen et al., 2014). This requires carbon black, 1-methyl-2 pyrrolidone (NMP) as a solvent, and polyvinylidene fluoride (PVDF) as a binder, along with heat and electricity (ecoQuery, n.d.-a). The process generates wastewater and spent NMP solvent. A similar process takes place to create the anode, which is made of graphite or silicon coated on a copper current collector. The finished electrodes are assembled with a separator and sealed in a container filled with electrolyte solution. The electrolyte is typically lithium hexafluoride, which reacts with water (Barlow, 1999; Yang et al., 2010). The process must therefore take place in a dry room, where the temperature, humidity, and air quality are strictly controlled (Ahmed et al., 2016).

Dry rooms are energy-intensive, which is the main driver of energy use for cell production (Dai et al., 2019; Kelly et al., 2019).

My foreground inventory for cell assembly is based on the ecoinvent u-so dataset (Table A1d). As in other production steps, I used the ecoinvent global market datasets for all inputs so that transportation impacts are included. The following parameters were altered to reflect local conditions: (1) Cathode flows use the output of the preceding calculations. (2) Electricity and heat inputs reflect scenario assumptions provided in Table 2.1. (3) US Polyethylene is used instead of global.

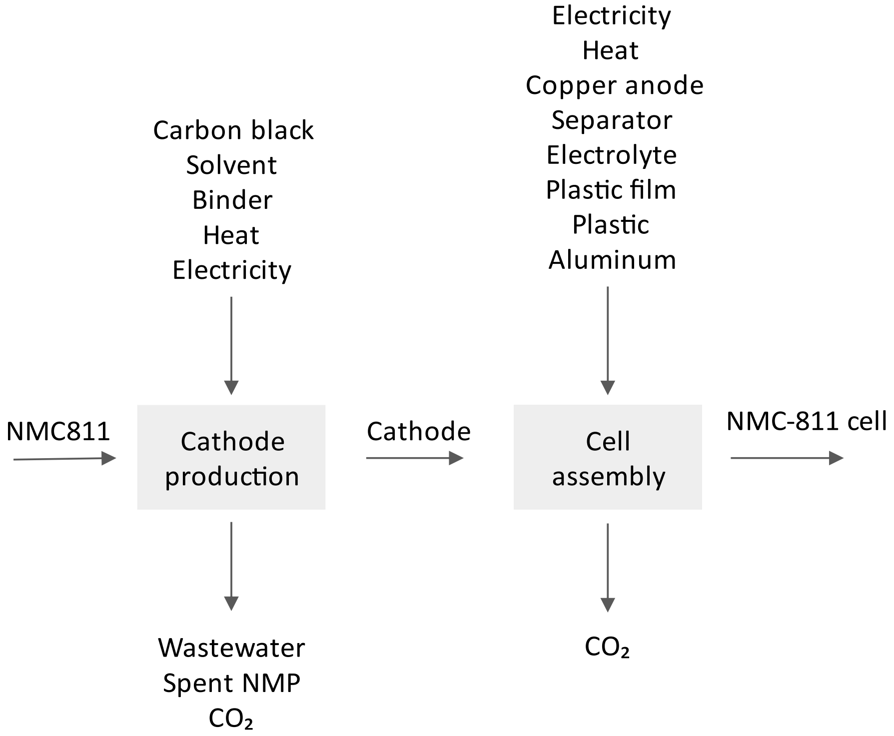


Figure 2.4: Flow diagram for cathode production and cell assembly.

Local Impacts

To evaluate the local impacts, I collected data about water use and waste generation from publicly available reports about similar planned facilities (Table 3). The water intensity for lithium extraction is based on water allocations that have already been established for two companies planning to pursue DLE in the region: ESM and Controlled Thermal Resources (CTR). The estimated water intensity for geothermal energy production and waste for geothermal and DLE is from (Dobson et al., 2023). Data for CAM and cell manufacturing are taken from environmental impact assessments (EIAs) prepared by the US Department of Energy for facilities that received federal loans from the Bipartisan Infrastructure Law: Ascend Elements' planned pCAM and CAM plant in Hopkinsville Kentucky, and the SK BlueOval campus in Glendale, Kentucky, which will produce LIB cells (DOE, 2023b, 2023a).

Next, I estimated the production capacity of a hypothetical battery hub by calculating how much CAM and cell production the announced lithium extraction facilities could support based on the ecoinvent inventories (i.e., assuming a requirement of 0.246 kg LiOH per kg CAM). I assume a cell energy density of 257 Wh/kg, which is the average of two cells analyzed in Campagnol et al. (2021). I then calculated the energy required to support the estimated level of production based on process heat and electricity values from the ecoinvent life cycle inventories. I evaluate the energy and power demand in the context of the Salton Sea geothermal reservoir, which is estimated to have a production capacity of 2,950 MW (Kaspereit et al., 2016). 400 MW have already been developed, and another 520 MW is planned to supply low-carbon grid electricity. This leaves approximately 2,030 MW or 17.8 TWh to support a potential battery hub.

Finally, I estimated the anticipated water use and waste generation for this level of production. Water in Imperial Valley comes from the Colorado River and is managed by the local utility, which has an annual allocation of 3.1 million acre-feet per year (AFY) (Shields, 2021). At present, roughly 97% of the allocation goes to agriculture, with the remainder split between industrial and municipal consumption (Dobson et al., 2023). To enable the expansion of lithium and energy production in the area, the utility has set aside an additional 25,000 AFY for industrial use. I evaluate the estimated water demand in the context of this 25,000 AFY industrial allocation.

Table 2.3: Energy and water consumption factors used in local impact assessment.

Product	Units	Water (m3 per unit)	Energy (MWh per unit)	Notes
LiOH	MT LiOH	275.7	7.7	Annual production based on CTR and ESM projects. Process water consumption based on water allocations for these developments. Waste analysis is based on Dobson et al., 2023.
pCAM + CAM	MT CAM	15.9	17.6	Water and waste is based on the EIA for Ascend Elements' planned precursor and cathode active material plant in Kentucky.
Cathode + Cell	MWh cell	20.2	31.4	Water and waste analysis is based on the environmental assessment report for the SK Blue Oval campus in Kentucky.

Results

Life Cycle Assessment

LiOH production. The estimated climate change impact of LiOH produced with geothermal DLE is 7.2 kg of carbon dioxide equivalent (CO_2e) per kg LiOH. This is 52% lower than the default ecoinvent LiOH dataset, which produces 15.1 kg CO_2e per kg LiOH. However, when the sources of $LiCO_3$ are disaggregated, LiOH produced via brine evaporation has the lowest carbon footprint of the potential pathways (6.3 kg CO_2e), while LiOH from spodumene has the highest carbon footprint (20.5 kg CO_2e, Figure 2.5). The results are similar in other impact categories, with DLE and brine having the lowest impact, and spodumene the highest (Figure 2.6). A table with the results for all impact categories is provided in the Appendix (A2.3).

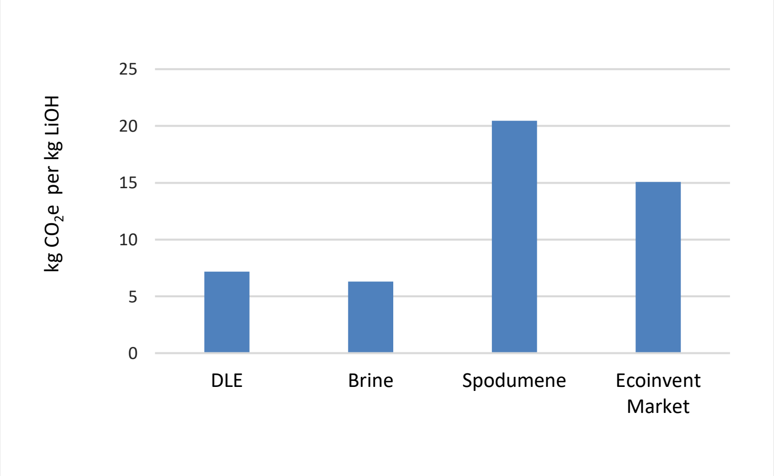


Figure 2.5: Global warming potential of LiOH production pathways in kg CO_2e per kg LiOH.

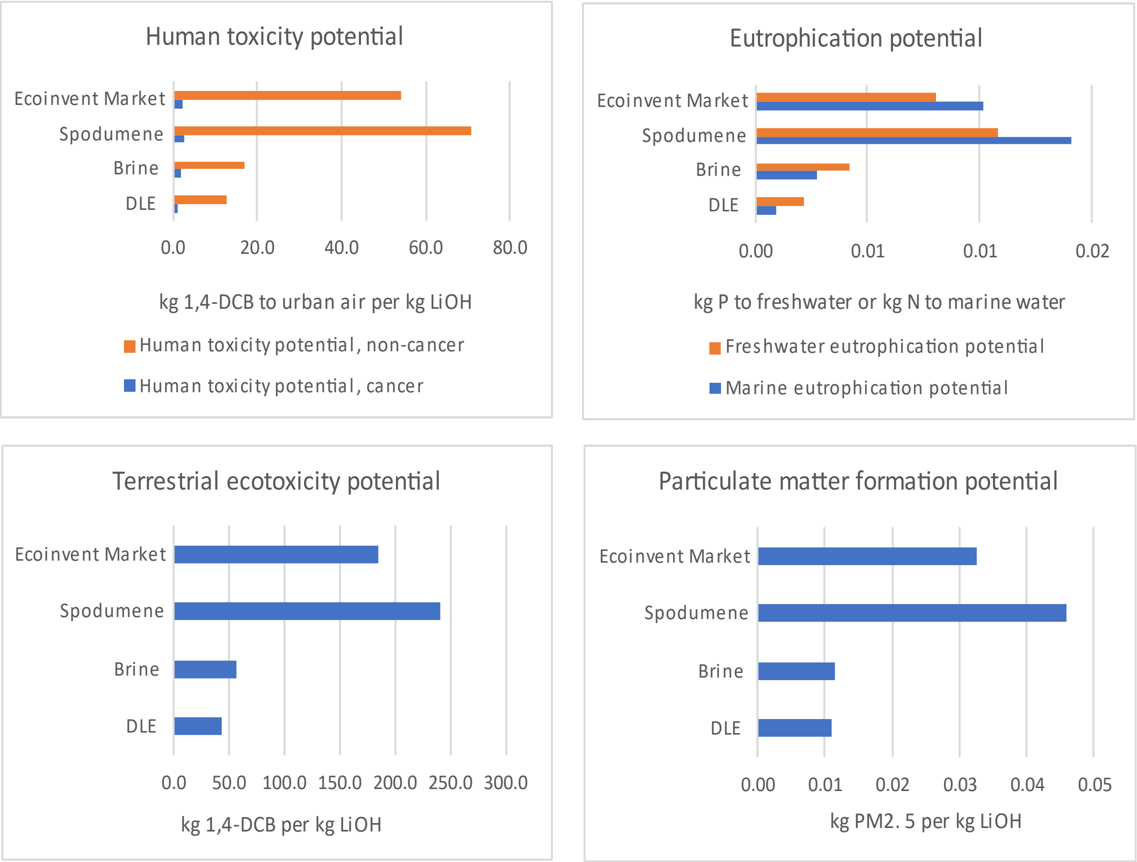


Figure 2.6: Results for human toxicity potential, eutrophication potential, terrestrial ecotoxicity potential, and particulate matter formation potential.

Pretreatment has a noticeable impact on GHG emissions (Figure 2.7); without it, the climate change impacts of DLE would be lower than brine evaporation at 5.89 kg CO_2e per kg LiOH. According to the process described in the patent I used (Featherstone et al., 2020), CO_2 is emitted as a byproduct of the pretreatment process at a rate of five moles per mole of solid waste, which translates to over one kg CO_2 per kg LiOH (Appendix A2.2). This highlights the importance of including pretreatment and waste disposal in LCAs of lithium. The level of pretreatment is dictated by the composition of the brine and the DLE technology used and will vary across developments. The process of converting $LiCO_3$ to LiOH is also a meaningful contributor to GHG emissions (Figure 2.7).

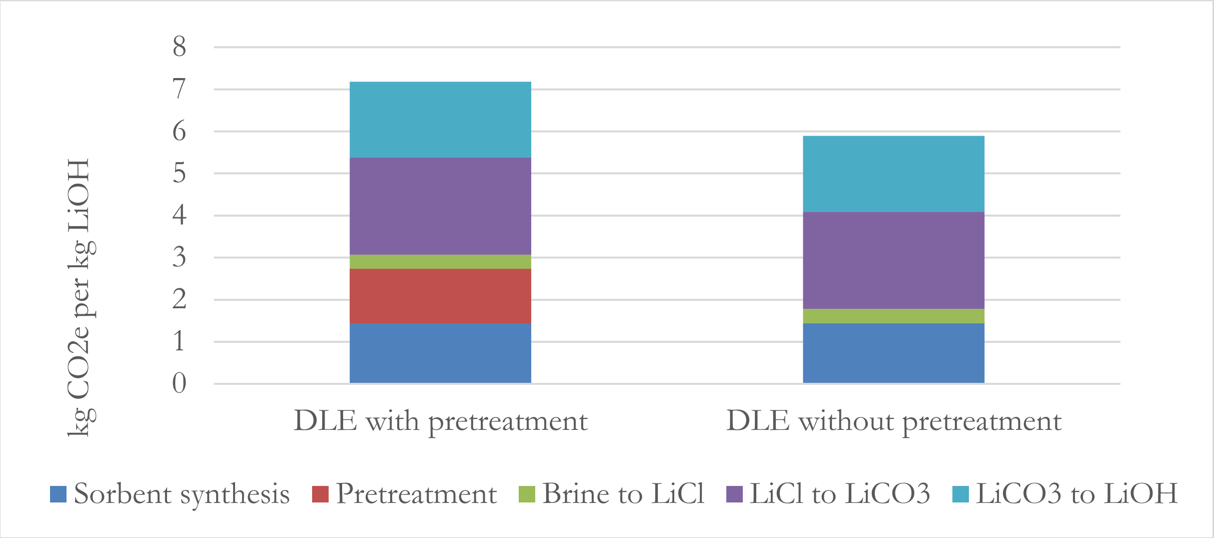


Figure 2.7: Global warming potential of DLE differentiated by production step, with and without pretreatment.

pCAM and CAM production. NMC 811 CAM produced with geothermal energy and DLE lithium yields the lowest carbon footprint, approximately 14.9 kg CO_2e per kg CAM produced (Figure 2.8). The second lowest-impact pathway is to produce CAM using geothermal process energy but imported market lithium (16.9 kg CO_2e). Using DLE lithium but conventional energy inputs in California increases the GHG impact to 19.3 kg CO_2e. Producing the battery in the Southeast US increases the GHG impacts to 22.1 kg CO_2e when using market LiOH. The ecoinvent dataset representing production in China has the highest impact at approximately 24.5 kg CO_2e per kg CAM.

LiOH is a relatively small fraction of the CAM by weight; according to the ecoinvent datasets, producing one kg of CAM requires 0.949 kg of pCAM and 0.246 kg LiOH. Other materials must be produced and shipped in greater volumes, particularly nickel sulfate (1.22 kg per kg CAM) and sodium hydroxide (0.81 kg per kg CAM) for an NMC 811 battery. Thus, reducing the environmental impact of LiOH has a limited influence on the overall impact of CAM production.

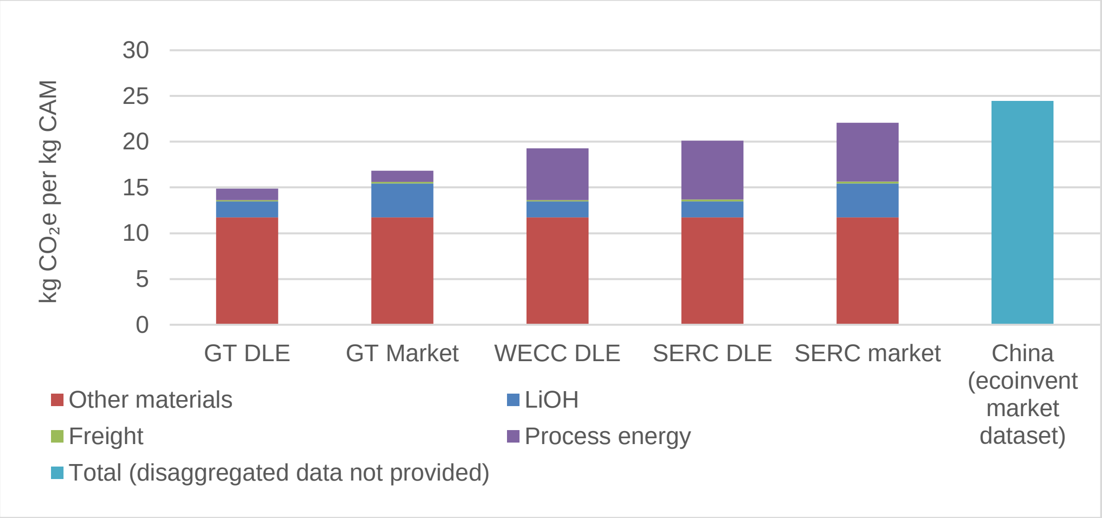


Figure 2.8: Global warming potential (measured by kg CO_2e) of different CAM production scenarios, differentiated by emissions driver (materials, freight, and process energy).

Nonetheless, it is still useful to know what is driving the benefit of using locally sourced geothermal lithium. There are two potential factors: the lower-carbon production pathway, and the reduced freight distance. According to this analysis, 98% of the difference between the market and DLE geothermal scenarios is due to the lower-impact LiOH production process, while the remaining 2% is because of the reduced need for freight (Table 2). This indicates that while reducing freight for specific materials may offer meaningful logistical and economic benefits, investing in lower-impact mineral extraction and refining is more important from a climate change mitigation perspective.

Table 2.2: Relative contributions of freight and LiOH production to overall global warming potential of CAM produced with geothermal energy.

GWP (kg CO2e/kg CAM)	GT DLE Scenario	GT Market Li Scenario	Difference
Total	14.87	16.85	1.98
LiOH production	1.77	3.70	1.94
Freight	0.00	0.04	0.04

Cell production. The breakdown for cell production scenarios is similar to CAM. An NMC 811 cell produced with geothermal energy and lithium from DLE has the lowest carbon dioxide emissions (10.9 kg CO2e per kg cell). The difference is marginal (0.7 kg CO2e per kg cell) between different cells produced with geothermal energy, even when using conventional LiOH (Figure 2.9). The CO2e emissions are 36% higher for the battery produced using conventionally-sourced LiOH and the SERC grid mix, and 51% higher for a battery produced in China. CAM production represents approximately half the total impact in all scenarios.

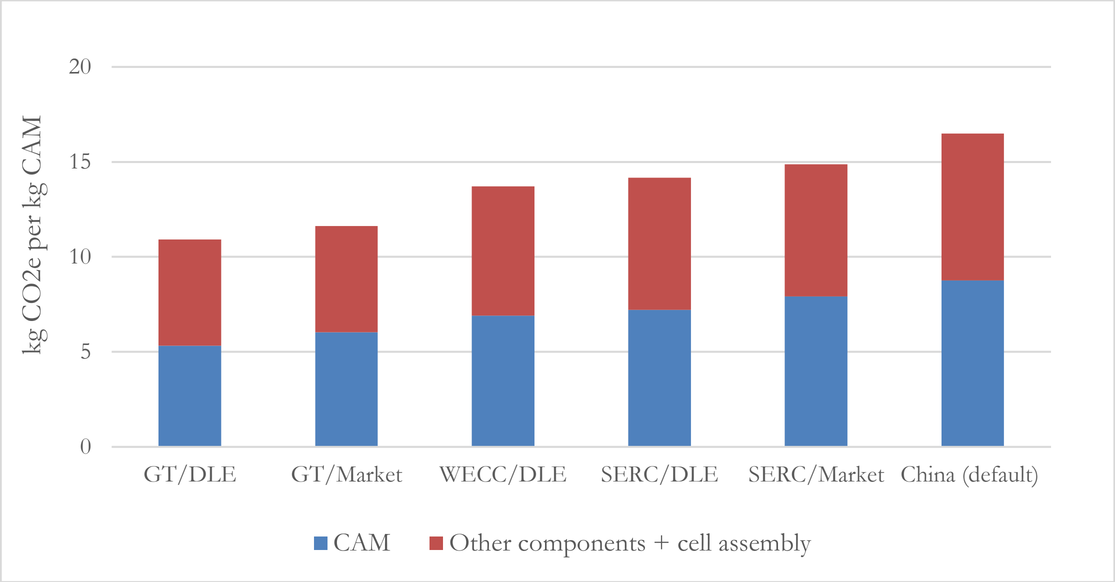


Figure 2.9: Global warming potential of lithium-ion battery cells produced under different scenarios.

Local Impact Results

The announced lithium production capacity to date is 44,000 MT LiOH per year. If all 44,0000 MT were used in local manufacturing, this quantity could support approximately 179,000 MT of CAM and 128 GWh of lithium-ion battery cell production per year. The estimated remaining capacity of the geothermal resource (2030 MW) is enough to power a hub with this level of production, but the cumulative water consumption would exceed the available water that has been allocated for industrial use. I therefore calculated a level of production that could be fully supplied by the established water allocation, assuming the same lithium output (44,000 MT per year). We find that the current water allocation could support approximately 106 GWh of CAM and cell production per year, which would use roughly 83% of the lithium produced onsite (36,700 MT). This would require developing an additional 715 MW of geothermal production capacity, or roughly fifteen 50 MW power plants. We refer to this level of production as the "Sustainable Hub" scenario.

Water use. CAM and cell manufacturing are less water intensive than LiOH production, representing 7.6% and 7% of the available industrial water allocation under the sustainable hub scenario, compared to 39% for LiOH production (Figure 2.10). The largest driver of water consumption is the expansion of geothermal energy to power the combined manufacturing processes. However, the water consumption for geothermal may be overestimated, as we use the estimated consumption rate for electricity as a proxy for both heat and electricity. Using geothermal for direct process heat would likely consume less water because it would not require cooling towers.

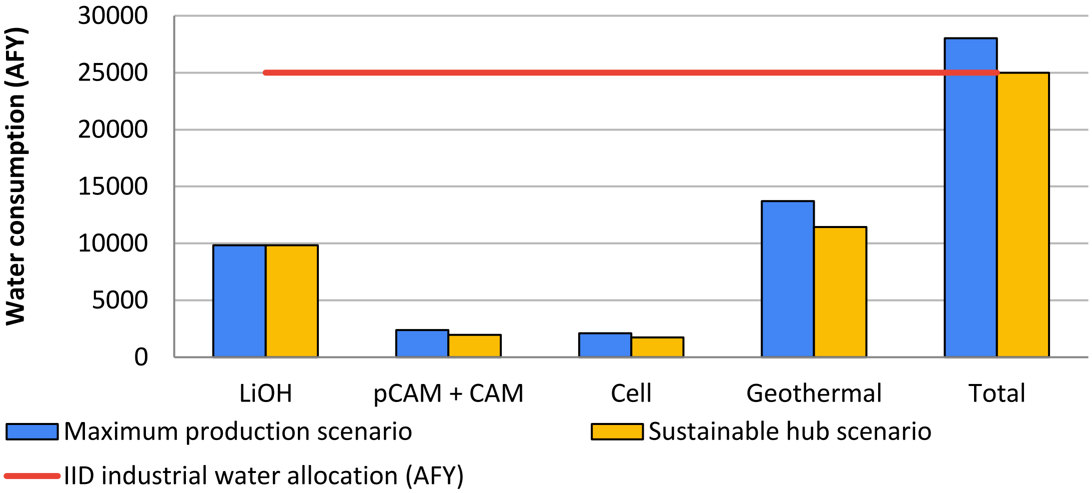


Figure 2.10: Estimated annual water consumption for LiOH, CAM, cell, and geothermal energy consumption, with red line indicating the existing industrial water allocation. The blue columns show the water consumption if 100% of announced lithium production is used for local manufacturing. The yellow columns represent the "Sustainable Hub" scenario, where manufacturing is limited to a level that would not exceed the available water allocation.

Because LiOH is more water intensive, expanding LiOH production beyond the planned 44,000 MT capacity would meaningfully limit the potential for regional manufacturing unless water were to be reallocated from agriculture. Doubling LiOH production to 88,000 MT would use 79% of the water budget, limiting CAM and cell production capacity to approximately 30 GWh (see Appendix Table A2.4.3).

Energy demand. If all lithium is utilized locally, the cumulative energy consumption of lithium extraction and CAM and cell manufacturing is estimated to be 7.5 TWh per year, which is roughly 60 GWh per GWh of cell produced. The additional power required to supply this level of production is approximately 860 MW, or just over seventeen new 50 MW geothermal power plants. However, as stated above, this level of production exceeds the allocated water supply. The Sustainable Hub is estimated to demand 6.3 TWh per year, which would require an additional 715 MW of geothermal capacity.

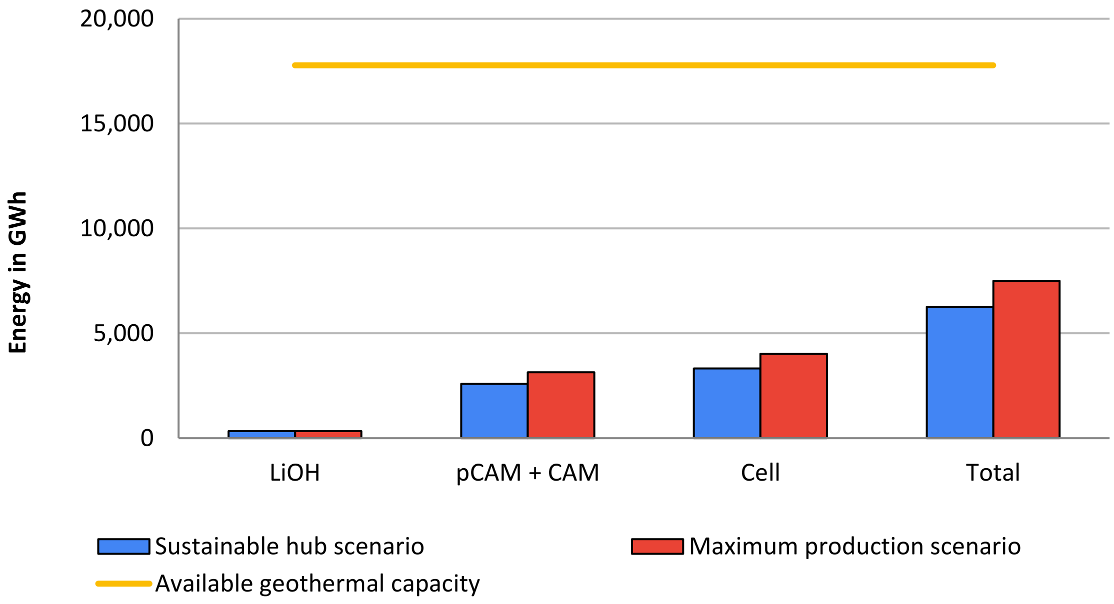
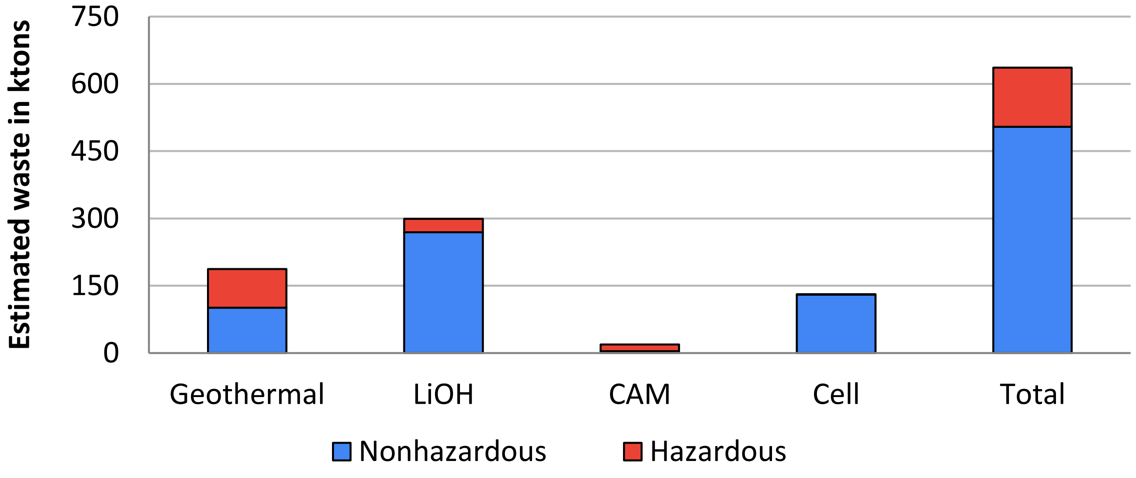


Figure 2.11: Estimated annual energy consumption for LiOH, CAM and cell production, with yellow line indicating the available capacity from the geothermal reservoir.

Waste streams. I estimate the "Sustainable Hub" would produce approximately 500 kilotons of solid waste per year (Figure 2.12). 24% of the waste would likely be classified as hazardous according to California standards, mainly filter cake from geothermal power and DLE. However, the amount of solid waste that is eventually landfilled depends on the extent to which waste materials are recycled or utilized for other products. According to the Blue Oval EIA, 99% of the waste generated at the cell production facility should be recyclable. I estimate that the sustainable hub production level would generate approximately 14,000 MT of electrode scrap per year, which could eventually provide feedstock for recycling. The appendix contains information about the estimated quantity and type of waste that is anticipated from each process (A5).

The main source of solid waste for DLE is the pretreatment process, which precipitates and removes impurities and competing ions such as silica, iron, calcium, and magnesium. The DLE process is estimated to generate 6.8 MT of solid waste per MT LiOH produced (Chambers Group, Inc., 2021). The main source of waste for CAM production is purification sludge from metals recovery, which represents an estimated 15,000 MT per year under the Sustainable Hub scenario.

Figure 2.12: Quantity of estimated annual waste generated by production step, differentiated by hazardous vs. non-hazardous.



The main driver of waste from cell assembly is spent solvent from the cathode production process, which is 1-methyl-2-pyrrolidone (NMP) scrap (Figure 2.13). NMP scrap can be recycled, and, therefore, was not classified as hazardous waste by the Blue Oval EIA, but it requires safety precautions to handle and transport (ECHA, 2008; National Center for Biotechnology Information, 2024). It is classified as a skin, eye, and respiratory irritant and reproductive toxin by the European Chemicals Agency and requires a U.S. Department of Transportation combustible liquid label. The U.S. Environmental Protection Agency identified chronic and acute exposure risks for workers who are exposed to NMP for over four hours without specialized protective gloves (Kramek, 2015; U.S. EPA, n.d.). The cell factory is estimated to generate over 73,000 tons of spent NMP per year under the Sustainable Hub production level, representing 65% of all waste from cell assembly (Figure 2.13).

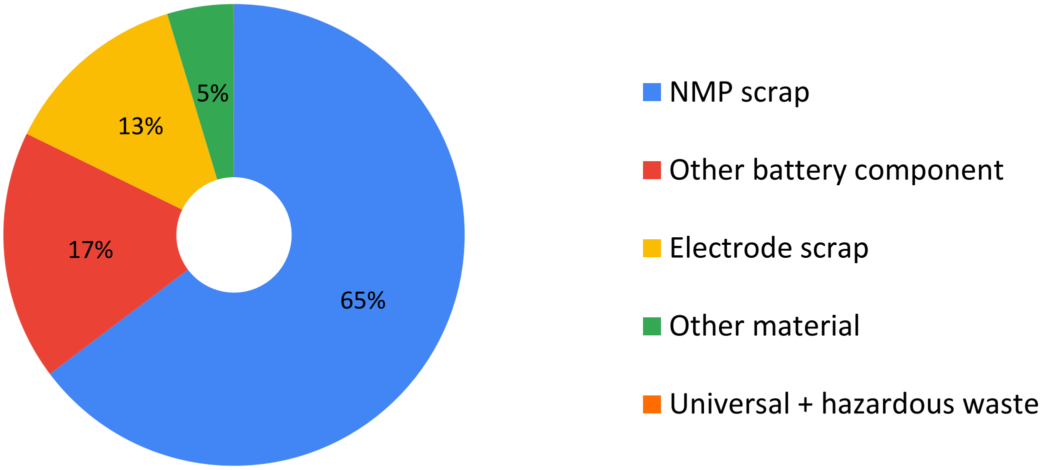


Figure 2.13: Waste streams from sample battery cell plant as a percentage of the total waste generated (DOE, 2023a).

Discussion and Conclusion

I find that a battery produced in a hypothetical geothermal hub has the lowest emissions of all pathways; however, most of the reductions are due to the use of geothermal energy, rather than avoiding shipping or using a lower-carbon source of lithium. From a decarbonization perspective, these results indicate that policymakers should prioritize developments that directly use low-carbon energy inputs and focus on cleaning up the electric grid in areas that support manufacturing. This is consistent with recommendations from previous studies (Hung et al., 2021; Kelly et al., 2019).

By this measure, the abundant geothermal resource makes the Salton Sea region a desirable location for a battery manufacturing hub even if lithium is imported from a conventional source, suggesting that there is reason to invest in local manufacturing capacity regardless of whether DLE proves scalable. However, to fully realize the environmental benefits, future geothermal power plants would need to be designed to produce both electricity and process heat, rather than optimizing for electricity production and mineral recovery only. Further study is recommended to understand the feasibility of coupling geothermal heat and power generation with manufacturing and accurately evaluate of the benefits. It should also be noted that we did not consider what else could have happened to the geothermal energy that would power the hub. Our "remaining capacity" estimates assume that all existing and planned geothermal energy goes to the grid, and anything else would be developed specifically for manufacturing. However, it's possible that additional geothermal capacity would be developed and displace natural gas on the electric grid if it were not used for manufacturing.

Collocating near a lithium resource has a less significant impact on overall GHG emissions because freight is a relatively minor driver of total life cycle impact, and lithium hydroxide is a relatively small percentage of the battery cell by weight. However, there are other benefits to collocating production near a lithium resource. From a local perspective, manufacturing would create more jobs than mineral extraction, and enable the region to capture more of the economic value from the resource (Benner et al., 2024). Collocating multiple manufacturing steps also facilitates improved communication and efficiency, as producers can easily send materials and samples back and forth. Locating CAM manufacturing near LiOH production also eliminates unnecessary logistical burdens; LiOH producers can directly mill the product to the correct size for CAM synthesis, rather than first milling it to a size that will allow it to be transported. Collocation also reduces the need to maintain excess inventory, which further reduces cost (Sizemore, Tracy, personal communication, October 19, 2023). Finally, while lithium is a small percentage of the battery cell by weight, it is the only non-substitutable element in lithium-ion batteries, meaning it will likely continue to be used even as cathode chemistries evolve. In other words, it still makes sense to locate near a lithium resource, even though there is more nickel than lithium in an NMC 811 battery.

With respect to local impacts, one of the key findings is that the allocated industrial water supply is insufficient to meet the cumulative demand if 100% of all the announced lithium production (44 ktons LiOH per year) is utilized for local battery production. However, the available water could support 106 GWh of CAM and cell production, which would use 83% of the lithium locally and still be by far the largest battery production hub in the United States.

If lithium extraction expands beyond the planned 44 MT of production, it will limit the potential for geothermal-powered manufacturing or require water to be reallocated from agriculture. From a national perspective, it may make sense to prioritize lithium extraction, as the Salton Sea geothermal resource is one of the largest domestic deposits and could meaningfully reduce reliance on imports for critical minerals. However, from a local perspective, prioritizing manufacturing would create more skilled jobs. Either way, this finding raises the importance of considering industrial developments through the lens of a water budget, rather than pursuing maximal production without considering environmental constraints. How water is allocated within this budget should be determined with the informed and meaningful participation of impacted communities.

Analyzing similar facilities raised several issues surrounding waste that warrant further attention. Regional landfill capacity will need to be evaluated to ensure it is adequate to manage the cumulative volume of waste expected to be generated by the Hub, and some of the waste may require specialized management. For example, filter cake that exceeds California's thresholds for hazardous waste designation will need to be sent to an industrial landfill in Arizona or a hazardous waste landfill in California. Meanwhile, the use of NMP as a solvent will require rigorous safety protocols to be followed during production, and the spent NMP will need to be sent to a solvent recycling facility. Researchers are currently investigating lower-impact solvent recovery methods (Green Car Congress, 2022) and non-NMP solvent alternatives (Li et al., 2020; Sliz et al., 2022).

Waste can be mitigated by identifying productive uses for silica filter cake and other solid byproducts from lithium extraction and verifying that any recyclable materials generated by cell assembly are sent to a recycling facility. Approximately 13% of the waste stream is expected to be electrode scrap, which will contain critical minerals such as nickel, cobalt, and graphite. As production scales up, adding battery recycling capacity to the hub could provide a local source of critical minerals beyond lithium.

One of the limitations of this study is that we rely on ecoinvent for our life cycle inventory data, which is helpful for carbon accounting and broad comparison, but is not place-specific. As a result, the inventories may not reflect the specific processes that would be used, and the local impacts of the LCA are less reliable. Additionally, we used the default ecoinvent data for all non-lithium components and materials, meaning the production pathways and transportation distances may not accurately reflect the supply chain for the Western US. We have attempted to address this limitation by including a separate evaluation of potential local impacts based on EIRs prepared for similar facilities. Future research could provide more accurate estimates by incorporating process data from existing facilities and regionally specific supply chains for other materials.

Another limitation is the focus on one single cathode chemistry, NMC 811, which enabled me to compare different production scenarios and identify the drivers of emissions reductions. However, cathode chemistry is a constantly changing landscape. NMC 811 has been expected to be the dominant chemistry for passenger EVs, but lithium-iron-phosphate (LFP) batteries have been gaining market share. LFP batteries have slightly higher lithium content an NMC 811, which would make the impact of using lower-impact lithium more significant and support the case for collocating near lithium instead of other resources. Additionally, LFP batteries use $LiCO_3$, meaning the added emissions from the process of converting to LiOH would be avoided. However, LFP batteries are also less energy-dense, meaning the potential hub production capacity in GWh would be lower for the same amount of lithium.

Finally, this study is limited to environmental impacts, and the local analysis is limited to water use and waste due to data availability. I did not address the impact on air quality or seismicity, which are high-priority concerns for residents and should be included in future studies. Scaling up geothermal and manufacturing capacity gradually, and with a plan for transparent monitoring, can help ensure that new developments do not increase the risk of earthquakes or cause other adverse impacts. Furthermore, I did not analyze socioeconomic factors such as community benefits and public participation, which are vital to addressing environmental justice issues. Focusing on quantifiable impacts enabled me to conduct a more rigorous technical analysis, which is necessary to inform sound policy decisions about sustainable manufacturing. However, environmental sustainability is just one piece of the just transition, and qualitative analyses of these socioeconomic dimensions is recommended for other studies.

Chapter 3: Charting the electric vehicle battery reuse and recycling network in North America

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Abstract

As electric vehicle (EV) sales rise, a common question arises: "what happens to the batteries?" Using expert elicitation, this study identifies the current pathways for retired EV batteries in the United States (US) and Canada and anticipates how the network might evolve. Most end-of-life (EOL) EVs are currently managed within the manufacturer and dealership network. However, more will enter the independent afterlife market as growing volumes reach EOL out-of-warranty. The interviews indicate that safety, transportation, and accessible information about battery composition and remaining capacity are critical issues across sectors. Participants demonstrated commitment to creating a closed-loop value chain, motivating novel partnerships between recyclers and producers. At the same time, the value of EOL batteries as a material supply source may create competition between recycling and repurposing in the short term. State and federal governments are implementing policies to facilitate access to information and incentivize domestic manufacturing. Still, compared to other countries, the US lacks a mechanism to ensure that batteries will be collected and recycled. In addition, there is no national tracking system that would provide more robust data on LIB management. Multiple participants noted that the network handles the majority of EOL batteries without significant policy intervention. However, the system depends on the economics of reuse and recycling when accounting for the cost of collection and processing, creating a risk of stranded batteries and/or wasted materials for packs that are lower-value or difficult to access.

Introduction

Electric vehicle (EV) adoption has shifted from aspiration to reality. Global EV sales doubled between 2020-2021, triggering a similarly rapid increase in demand for the lithium-ion batteries (LIBs) that power them (IEA, 2022). The impact of mineral extraction on local environments and human rights has come under scrutiny (Amnesty International, 2016; Arvidsson et al., 2022; Chaves et al., 2021; Liu & Agusdinata, 2020; Marchegiani et al., 2020; Sharma & Manthiram, 2020; Stamp et al., 2012), while, in parallel, disruptions caused by the COVID-19 pandemic and war in Ukraine have highlighted the fragility of complex global supply chains across sectors (IEA, 2022). As a result, policymakers, companies, and consumers alike are turning their attention to the sustainability and resilience of the lithium-ion battery (LIB) supply chain (Benchmark Minerals, 2021; International Energy Agency, 2021; Kendall et al., 2022).

One of the most promising solutions is to develop circular supply chains for LIBs, where materials are reused and recycled into new products, rather than perpetuating a linear system that extracts raw materials and disposes of them as waste (Baars et al., 2020; Gaustad et al., 2018; Kirti Richa et al., 2017). Circularity principles dictate that products be maintained in their highest and best use for as long as possible, then recycled so the constituent materials can be recovered (Blomsma & Brennan, 2017; Geissdoerfer et al., 2017; Webster, 2015). In the case of EVs, LIBs can also be reused in another vehicle or repurposed as stationary storage, extending the useful life and reducing demand for new products, thereby mitigating unnecessary mining impacts (Bobba et al., 2018; Casals et al., 2017; K. Richa et al., 2017). Meanwhile, recycled materials have lower greenhouse gas and sulfur oxide (SO_X) emissions than virgin materials and can provide a domestic supply for regions that would otherwise rely on imports (Ciez & Whitacre, 2019; Du et al., 2022; J. B. Dunn et al., 2015; Harper et al., 2019; Mayyas et al., 2019; Kirti Richa et al., 2014).

There are a variety of commercialized LIB chemistries for EVs, differentiated by the materials used in the cathode. A battery's material composition influences its cost and environmental and social impacts during production, which in turn influence the relative benefits of reuse and recycling. The environmental benefits of recycling are most significant for LIBs that contain nickel and cobalt, as these are the most energy- and pollutant-intensive materials to mine, which means the impact of the recycling process is significantly smaller compared to mining new material (Ciez & Whitacre, 2019; J. Dunn et al., 2022). Similarly, nickel and cobalt are also the most valuable materials in terms of commodity price and, therefore, are more profitable to recover in a usable form (Kirti Richa et al., 2017). Conversely, the relative advantage of repurposing batteries before recycling is greatest for batteries with lower-value cathodes such as lithium-iron-phosphate (LFP) or nickel-manganese-oxide (LMO).

When an EV LIB reaches end-of-life (EOL) is a function of its remaining capacity, which is typically reported in terms of the state of health (SOH). There is no single definition or method for calculating SOH, but it can generally be understood as an estimate of the battery's capacity to store energy compared to when it was first manufactured (Dubarry et al., 2020; Yang et al., 2021). EV LIBs are commonly considered to reach end-of-life (EOL) when their SOH reaches 80% or lower; however, in reality, the SOH at EOL varies, ranging from 60-80% depending on driver preferences, the vehicle's intended use, and the reasons for vehicle retirement. For instance, some drivers may continue operating a vehicle below 80% SOH if they use the vehicle for short trips and the range is still acceptable to them. As a result, the expected average lifespan is difficult to predict with certainty; most companies warranty their battery packs for eight years, while researchers have estimated the majority will retire after 10-12 years (Fallah & Fitzpatrick, 2022).

The SOH also determines the suitability of batteries for reuse and repurposing. The SOH required for various applications is not well established due to the nascency of the industry, but 68% SOH has previously been considered a lower bound for repurposing (Lacap et al., 2021). Repurposing is still a novel phenomenon, but it is estimated that it can extend the battery's usable life by 10-15 years, depending on the application (Lacap et al., 2021; Neubauer et al., 2015; Fallah & Fitzpatrick, 2022). For example, grid stabilizing services have relatively low performance demands, yielding a longer extended lifespan or providing a valuable option for LIBs that have degraded below 80% (Fallah & Fitzpatrick, 2022). Meanwhile, if an EV is retired due to a collision, the battery may have a SOH well above 80% and be suitable for reuse in another EV after the battery has passed a collision assessment.

While technical aspects of reuse and recycling continue to be extensively studied and reviewed, the logistics of collection and transportation are commonly omitted or included in vague terms in research about vehicle EOL management (Slattery et al., 2021). As a result, there is a knowledge gap surrounding the practical pathways EV batteries that are retired today follow once they are removed from a vehicle. This is particularly the case in North America, where afterlife vehicle management is a market-driven industry, and the fate of LIBs is not dictated by policy (Saidani et al., 2019).

The lack of readily available data opens the door to misinformation and potentially contributes to the public perception that the batteries are not recyclable or recycled at a very low rate (Dreibelbis, 2022). While increased consumer awareness about recycling could motivate companies to implement more sustainable practices, excessively pessimistic misinformation might raise unwarranted alarm and delay the transition from fossil fuels. Accessible information regarding the existing landscape is necessary to redirect attention toward areas where policy and research are most needed and can make the greatest impact in ensuring the batteries are efficiently reused and recycled. In addition, researchers analyzing the environmental and economic impact of EVs require accurate information about EOL pathways to justify assumptions such as transportation distance, whether batteries are reused before recycling, what recycling process is used, and what materials are recovered.

To chart a course for sustainable LIB management, this study uses expert elicitation to answer the following research questions: (i) what are the current EOL management pathways for EVs and their batteries? (ii) how do stakeholders expect their industries to change as higher volumes of EVs are retired? And (iii) what policies are needed to create a safe and effective closed-loop system for EV batteries in the US?

We interviewed stakeholders in industries that handle EOL vehicles and batteries, including auto manufacturing, auto dismantling, scrap metal recycling, battery collection and logistics, battery repurposing, and battery recycling. The interviews were transcribed and analyzed to generate a comprehensive overview of the existing network, as well as insights about how different sectors have been impacted by vehicle electrification, how stakeholders expect things to change in the future, and areas of concern and opportunity. Next, we discuss trends in battery chemistry and design, safety, and access to information, which were common themes across all stakeholder groups. Finally, we identify policy recommendations for creating a closed loop for EV batteries in North America.

For the purposes of coherence and feasibility, the scope of this article is limited to LIBs from battery EVs (BEV), specifically passenger cars, which represent roughly 79% of electric vehicle sales in 2022 for North America (Figure 3.1; IEA, 2023). We do not address LIBs from plugin-in hybrid or hybrid EVs (PHEV and HEV), nor from electric buses, bicycles, motorbikes, or scooters, all of which represent significant and growing volumes of EOL LIBs and warrant further study. While the recycling process for LIBs will ultimately be the same, the logistics and management networks differ across these applications due to cost, size, voltage, and ownership structure.

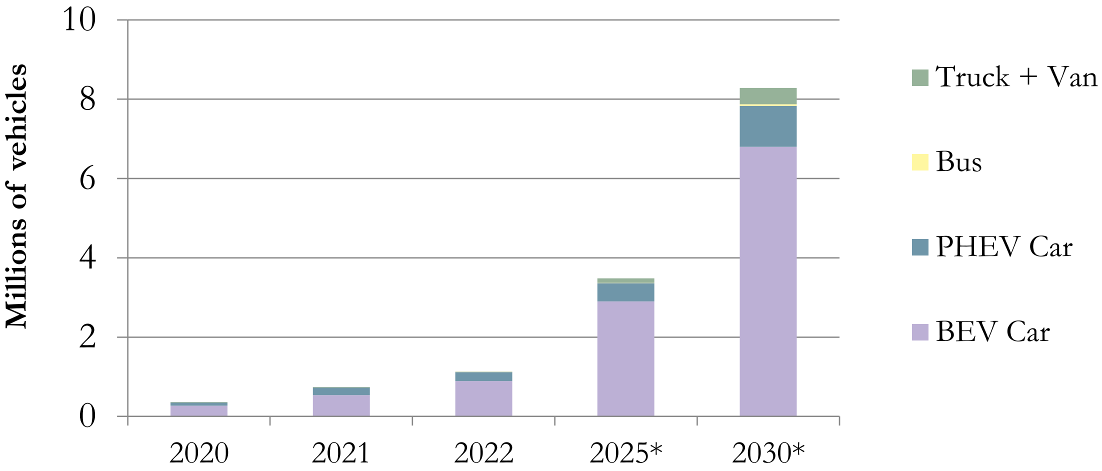

*Figure 3.1: Historical and projected electric vehicle sales in Canada, Mexico, and the United States (US) by drivetrain, excluding 2-and 3-wheelers due to data unavailability. Data source: International Energy Agency, 2023. * = US only.*

Methods

We interviewed 29 participants who work in sectors that manage EOL vehicles or LIBs (Table 1). The interview schedule is provided in the Appendix (A3.1). Participants spoke from their experience working in relevant industries and did not represent the official viewpoint of their company or organization. Initial participants were recruited by emailing companies and trade associations that participate directly in auto and battery recycling. During each interview, we asked participants if there were other people or organizations they thought we should talk to. Additional industries were included as we learned of their connection to EOL LIB management; for example, auto insurance auctions, sorting and storage companies, and auto original equipment manufacturers (OEMs). The interviews took place between December 2020 and September 2022 and were held virtually due to the COVID-19 pandemic. We continued conducting new interviews until 1) the interviews yielded repetitive information regarding sectors and processes involved in the reuse and recycling network, and 2) we had spoken with at least one representative from each sector that had been identified.

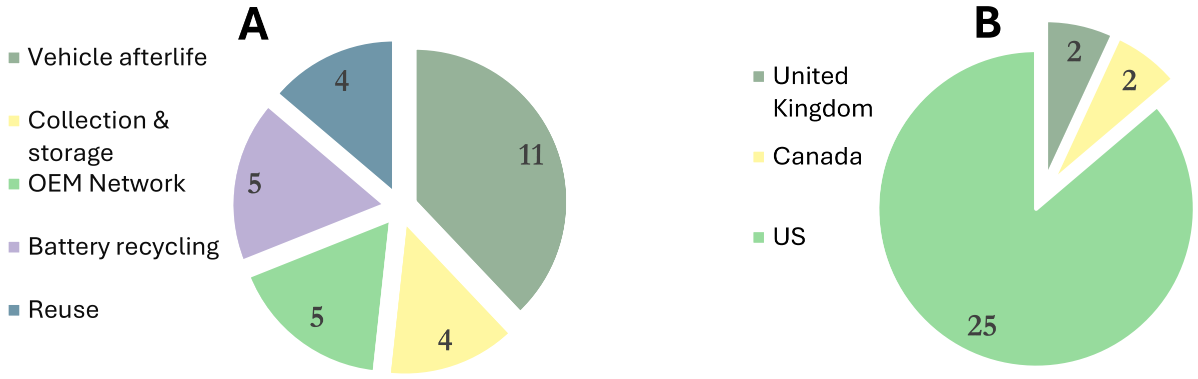

Figure 3.2: Number of participants by sector (A) and location (B).

Table 3.1: Participant list

ID	Stakeholder Group	Company Description	Location	Date	Transcript
P1	Vehicle afterlife	Auto dismantler	Western US	9/22/20	No
P2	Vehicle afterlife	Auto dismantler	Western US	11/5/20	Yes
P3	Vehicle afterlife	Consultant for auto dismantling industry	UK	11/5/20	Yes
P4	Collection & Storage	Battery stewardship organization	Canada	11/17/20	Yes
P5	Vehicle afterlife	News editor for auto recycling industry	UK	11/18/20	No
P6	Collection & Storage	Battery sorting and storage company	US	11/19/20	Yes
P7	Vehicle afterlife	Auto dismantler	Western US	11/23/20	Yes
P8	Vehicle afterlife	Auto recycling trade association	US	11/24/20	No
P9	OEM Network	Automotive parts supplier	US	11/30/20	No
P10	Battery recycling	Battery recycler	Canada	12/1/20	Yes
P11	Reuse	Battery diagnostics company	Eastern US	12/3/20	No
P12	Collection & storage	Battery sorting and storage company	US	12/4/20	Yes
P13	Vehicle afterlife	Scrap metal recycler	Western US	2/18/20	Yes
P14	Battery recycling	Battery recycling & collection company	US	3/18/21	Yes
P15	Reuse	Repurposing and diagnostics company	Western US	5/26/21	Yes
P16	Vehicle afterlife	Salvage auto auction	US	3/11/22	Yes
P17	Vehicle afterlife	Scrap metal recycling trade association	US	4/29/22	Yes
P18	Reuse	Repurposing and	Western US	5/22/22	Yes

		diagnostics company			
P19	Battery Recycling	Battery recycling and materials company	Western US	5/16/22	Yes
P20	Battery Recycling	Battery recycling and materials company	Western US	5/16/22	Yes
P21	Vehicle afterlife	Auto dismantler	US	5/24/22	Yes
P22	OEM Network	Dealership trade association	Western US	6/2/2022	Yes
P23	Collection & storage	Battery sorting and storage company	US	6/10/22	Yes
P24	Vehicle afterlife	Auto dismantler	US	6/13/22	Yes
P25	OEM Network	Auto industry trade association	US	8/25/22	Yes
P26	OEM Network	Automaker	US	8/26/22	Yes
P27	Reuse	Repurposer	Western US	8/26/22	Yes
P28	Recycling	Battery recycler	US	9/7/22	Yes
P29	OEM Network	Automaker	US	9/7/22	Yes

Two researchers reviewed the transcripts or interview notes, developed codes based on the research questions and prominent themes that emerged during the interviews, and then coded the transcripts using ATLAS.ti Windows 22, a qualitative analysis software (ATLAS. ti Scientific Software Development GmbH, 2022). The unit of analysis was one paragraph, meaning that when a speaker mentioned a theme, the corresponding code would be applied to the entire paragraph.

The code "network" was applied to any text where participants described their process, the channels through which they acquired vehicles or batteries, and their downstream customers or partners. These quotes were reviewed and synthesized to create a diagram and descriptions of the EOL EV network. The codes "impact to date" and "impact anticipated" were applied to text where participants described the effect vehicle electrification had on their industry and how they expected things to change in the future, then grouped and analyzed the responses by stakeholder category. We also applied a corresponding code whenever participants mentioned a challenge, concern, or opportunity presented by EV batteries.

Finally, the interviews were coded thematically based on topics that were mentioned by multiple participants (Table 3.2). The most frequently mentioned themes across stakeholder groups were information, battery design, policy and regulation, logistics, safety, and circular economy. In some cases, there were subcategories within these topics; for example, within the category of "information," we identified three distinct types of information mentioned by participants: (i) information about remaining capacity, or SOH, to evaluate potential for reuse; (ii) battery information, referring to battery specifications such as chemistry, format, and manufacturer; and (iii) instructions, such as how to remove and repair battery packs, safety protocol, and guidance on where to send battery packs.

There were a small number of instances where people had conflicting viewpoints, possibly due to competing interests. Any information that was directly contradicted by another participant was not included in the paper unless we could verify it through another source. The draft article was distributed for participants to review and confirm that any results or discussion attributed to them had accurately represented their perspective, which enabled us to validate the aggregated results from the interviews. Following their feedback, more detail was added to the existing network and anticipated challenges, primarily for the independent afterlife market and reuse and repurposing sectors.

__Table 3.2:__ Thematic codes with sample quotations from interviews and the number of times mentioned ("n").

Code	Subtopics	Example Quote	n
Battery information	Remaining capacity, instructions for removal, battery contents, sources of information	"I usually have no trouble figuring out if it's an iron phosphate or NMC. Or an NCA, but then digging deeper, what version of NMC is that? Or how much aluminum is in that NCA, I'm really at the mercy of what the manufacturers have put out onto the internet, data sheets and that sort of thing" (P12) "And… today, we want to know **what** they did 10 years ago. And…having that information, you know, available in a format that is accessible, it's certainly key… and when they were making that battery 10 years ago… they might not have been focused on this issue. And so… going forward again, it's a matter of having that partnership with OEMs." (P13)	58
Policy and regulation	General mention of regulation, extended producer responsibility, enforcement of existing laws	"For example, one of the European regulations is what we call extended producer responsibility…So if any of our recyclers and dismantlers here have got a battery that they can't sell and can't make any money on, then they just contact the manufacturer, Honda or Toyota or whoever, and just say come and pick it up. And they have to pick it up at no cost to the end user. So therefore, they're not losing money, they're not paying to dispose of it" (P3)	51
Logistics	Transportation and storage of batteries	"I think today, there's still a lot of, we're just at the very beginning of a	46

		learning curve. And so like transporting batteries is very expensive today, still, and I think people are learning how to safely and properly package them and things like that" (P29)	
Battery design	Battery chemistry, battery format	"One of the key things we also want to improve is right now, as I said, like we're shredding at the module level, but in the future, we believe we'll be able to shred at the pack level, which is going to be better for optimization. And the reason also for that is you'll see a lot of automakers going, skipping the module" (P10)	40
Safety	Fire, electric shock	"Safety, safety, safety's number one concern. I mean, I've heard a couple of stories where the cars show up in the auto recyclers, and they don't know where the kill switch is. In every vehicle pick, every manufacturer puts a master kill switch in there, but they're not in the same place." (P4)	31
Circular economy	Closed-loop supply chain, domestic manufacturing	"Our colleagues on the upstream side that are concerned with securing sustainable materials for our supply chain are also viewing recycling as a very strategically critical source of sustainable materials. So we kind of have interest from both ends, both from you know, the end of life vehicle, but also from the, like, the new raw materials to make our cells for the vehicles that are yet to be made" (P29)	26

Results

Existing Network

Analysis of the interviews informed the following diagram (Figure 3.3) describing the possible material flows from EOL EV batteries. The section below describes the stakeholders and processes involved at each step (initial retirement and removal from vehicle, reuse and repurposing, battery recycling, and collection and sorting). Our network description is consistent with a recent report about the network in Canada published by Call2Recycle, a product stewardship organization that facilitates battery collection in North America (Call2Recycle Canada & Canadian Vehicle Manufacturers Association, 2022).

Initial retirement and removal from vehicle. EV batteries may be retired due to a malfunction, diminished performance (e.g., the range was no longer acceptable to the driver), or physical damage. The specific pathway of the retired EV battery depends on its condition and whether it is under warranty. If the battery is still under warranty, an EV is returned to the dealership ("A" in Figure 3.3), where technicians diagnose the battery's remaining SOH and remove the pack from the vehicle. Based on the SOH, the OEM determines whether the battery should be refurbished or remanufactured for reuse in another vehicle, repurposed for stationary storage, or sent directly to recycling for material recovery. An important caveat is that this pathway reflects EVs that are sold by traditional OEMs; major US EV manufacturers including Tesla and Rivian do not follow the same dealership model. Further study is needed to delineate the varying strategies across manufacturers.

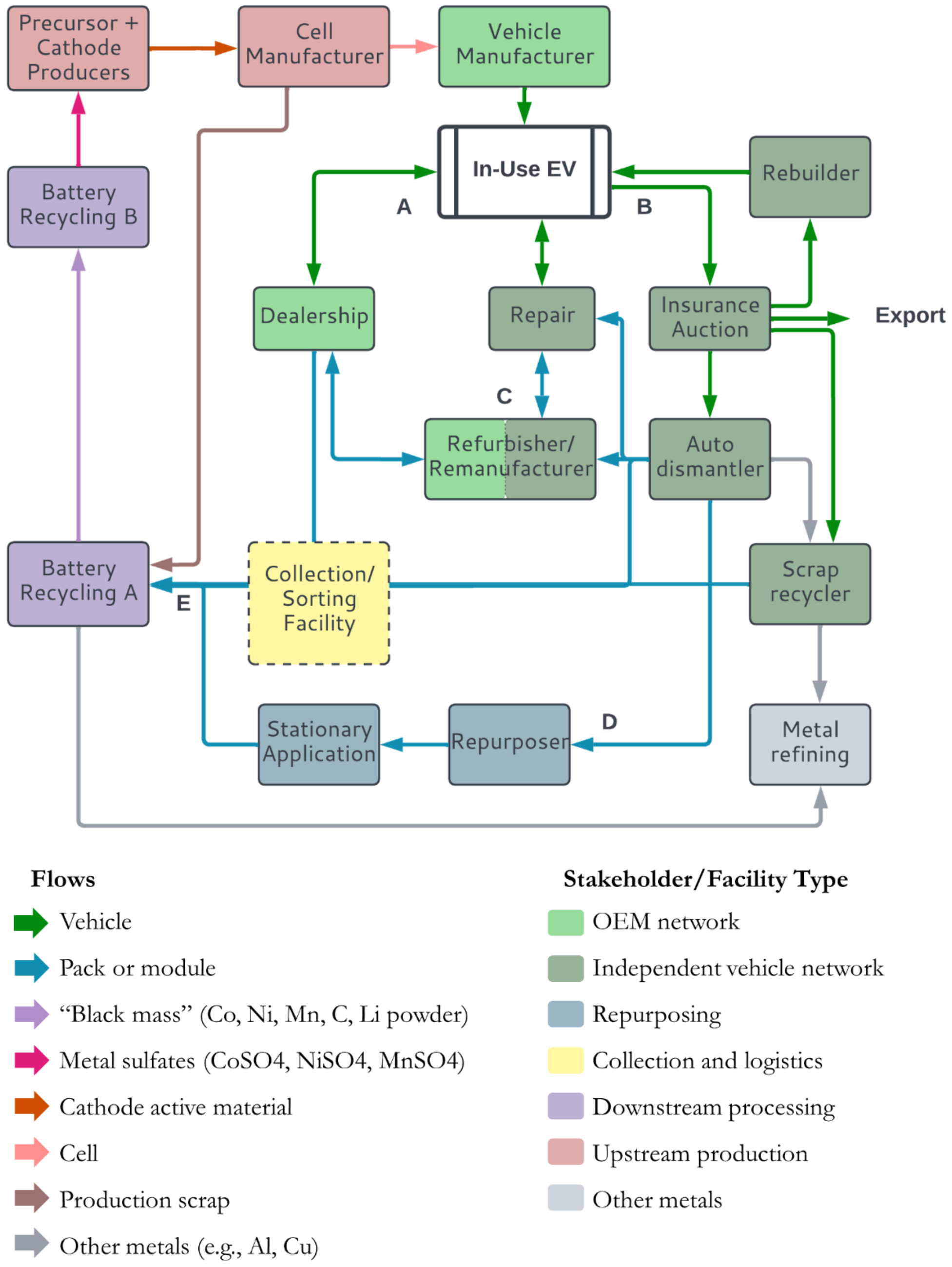

Figure 3.3: Product flows from EOL batteries. "A" represents batteries that are returned under warranty. "B" represents batteries that are removed due to a car collision. "C" represents batteries that are remanufactured or refurbished and reused in another vehicle, which could be performed within the dealership/OEM network (represented by the light green color) or by an independent operator (dark green). "D" represents batteries that do not have sufficient SOH for reuse in another vehicle but are repurposed as stationary storage. Batteries without remaining usable life may be aggregated at a collection facility or sent directly to a recycler. "E" represents all retired batteries and production scrap that are sent to a battery recycler. Battery recycling consists of two steps: pre-treatment ("Battery Recycling A") and material recovery ("Battery Recycling B").

EVs that are retired due to a collision are entering the existing vehicle afterlife market in small but growing volumes. Any vehicle that is retired due to a collision ("B" in Figure 3) is known as a "total loss vehicle" and becomes the property of an auto insurance company. These vehicles are sold at insurance auctions, where they may be bid on by members. Auto dismantlers typically acquire vehicles with parts that are still in usable condition, then remove the parts and sell them to repair shops, private individuals, and other dismantlers. Vehicles may also be purchased by rebuilders, who restore the full vehicle to working condition for resale, or by exporters who sell them in international secondhand markets. Older vehicles with little to no remaining value are purchased by scrap metal recyclers, who strip the parts, crush and shred the vehicle, and separate metallic and non-metallic components. The shredded metal is exported or sent to a domestic steel mill, depending on the location. With the exception of niche dismantlers who specialize in servicing full BEVs and larger corporations, most auto and scrap metal recyclers today mainly interact with traction batteries when handling hybrid vehicles (P1, P2, P7, P13, P24). However, in the future, auto dismantlers may be an important source of batteries to be reused in a vehicle or repurposed in a stationary storage application. Because they typically handle the oldest vehicles, scrap recyclers will likely be the last sector to start processing EOL EVs at scale (P13).

A third category of EV batteries will naturally reach EOL out-of-warranty. These may be removed and replaced at independent repair garages, and/or remanufactured to provide replacement battery packs. Out-of-warranty EOL EVs are likely to enter the independent aftermarket directly through a variety of channels: drivers or tow truck operators may sell them directly to dismantlers or scrap recyclers, or dismantlers and scrap recyclers may receive them from donation or state-run reclamation programs. However, due to the nascency of EVs, this has not yet happened at scale; the first mass-produced EV in the US was the 2012 Nissan Leaf, which had a battery warranty of 8 years [17]. As such, few EOL LIBs are managed outside the OEM and dealership networks today unless they are retired because of a collision. The pathways for these batteries are, therefore, outside the scope of our existing network description. However, they will be essential to consider for the future.

Reuse and repurposing. EV LIBs that are retired due to vehicle damage or defective cells may be restored to a like-new condition through refurbishing or remanufacturing. At a high level, refurbishers and remanufacturers diagnose SOH on a cell level, replace worn or defective parts, then reconfigure the cells or modules to produce a pack with uniform SOH. The last step is referred to as "rebalancing the modules." The difference between the two is that refurbishing is performed to restore new packs with minor defects to OEM-specifications, while remanufacturing restores used packs to a like-new condition by replacing worn parts. As the market grows and more battery packs retire out of warranty, independent remanufacturers may provide a more affordable alternative to OEM replacement battery packs.

Meanwhile, LIBs with a lower but still sufficient SOH may be repurposed for "second-life" use in a stationary storage application (P15, P18, P27). While the exact process varies by company, repurposing generally involves disassembling the pack into modules to break the chain of voltage, diagnosing the SOH of cells or modules, reconfiguring them to optimize efficiency, equipping the repurposed system with a new battery management system (BMS) and other software if the existing BMS is not available, and installing it in a shipping container or purpose-built battery enclosure (P15). This process may be simplified by repurposing at the pack level (e.g., (B2U, n.d.)). However, repurposing at the module level enables the system to have a longer lifetime and higher energy density, meaning repurposers can provide more energy storage with a smaller footprint and fewer shipping containers (P18).

Repurposed stationary energy storage systems are currently operating at the utility and commercial scale in North America and around the world, as well as in off-grid and mobile applications (Faessler, 2021). There are several demonstration sites in California that have been funded by the California Energy Commission to generate more robust information about the performance and durability of used batteries (Kendall et al., 2022).

Battery recycling. Eventually, the batteries will be sent to a recycler for material recovery ("E"). There is a growing network of lithium-ion battery recyclers in North America (Figure 3.4). While EV batteries are only a fraction of the recycler input today, this percentage will grow significantly over the next decade as EV uptake increases and more EVs reach their end of life.

There are two commercial processes for recycling LIBs: hydrometallurgical and pyrometallurgical, with additional novel recovery methods under development (e.g., direct cathode recycling) (Harper et al., 2019). In reality, each company has a unique process, with some combining pyro- and hydrometallurgical methods. This section describes the process used by the companies we interviewed, which is some version of mechanical pretreatment followed by hydrometallurgy. This is representative of most new facilities that have been announced in the past several years.

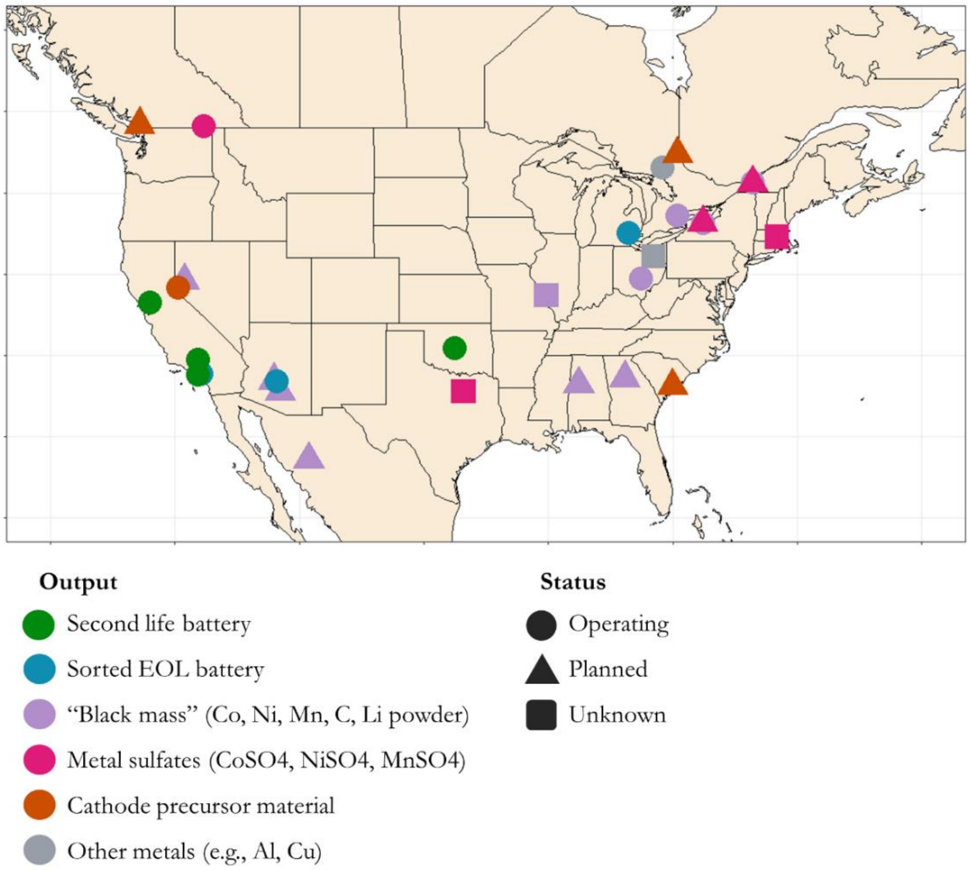

Figure 3.4: *Planned and operating infrastructure for handling EOL LIBs in North America at time of publication (NREL, 2022).*

The first step is to disassemble battery packs into modules by removing the outer casing and other battery system components such as the thermal management system, BMS, and wiring. Recyclers typically then shred battery modules and separate the electrode materials from other materials such as plastics, aluminum, copper, and steel. Some recyclers have developed the capacity to shred packs directly, particularly for damaged batteries (P28). The output of this pretreatment process is a powder containing manganese, nickel, cobalt, lithium, and graphite that is commonly referred to as "black mass." The specific outputs vary by company; for example, one recycling company avoids the term "black mass" altogether and produces intermediary products that are specifically designed for their downstream material recovery process (P19, P20).

The black mass (or other intermediary output) then undergoes hydrometallurgical processing to produce battery-grade material in the form of metal sulfates (e.g., $CoSO4$, $NiSO4$, and $MnSO4$) and lithium carbonate or lithium hydroxide. The infrastructure for pretreatment (module to black mass) exists at scale in North America today, but because there is little to no refining capacity, black mass is typically exported for further processing. However, there are several demonstration-scale domestic hydrometallurgical processing facilities, with one operational commercial facility and larger facilities under development (e.g., Gruba, 2022; Hawkins, 2022; Figure 2), which means more refining will occur in North America in the future.

Collection and sorting facilities. We interviewed participants from two companies that specialized in sorting and storage for EOL batteries (P6, P14, P12, P23), as well as a non-profit that coordinates collection and transportation (P4). The function of storage and sorting is to aggregate larger quantities of batteries that are sorted by chemistry, ideally achieving enough volume for a full truckload shipment (approximately 35-38,000 lbs. of batteries, according to P12) to maximize efficiency and minimize the shipping cost per battery. Both participating sorting companies historically processed other battery types (i.e., lead-acid, alkaline, NiMH, LIBs from consumer electronics), which are sorted to determine which downstream processor they should be sent to. All LIBs can be sent to the same processor; however, sorting them by cathode chemistry enables the sorter to negotiate, as recyclers may be willing to pay for batteries that contain nickel and cobalt (e.g., NMC or NCA) but not lithium iron phosphate (LFP) (P6).

Impacts of Vehicle Electrification and Expectations for the Future

This section discusses how stakeholders in each sector have perceived the impact of vehicle electrification on their sector, as well as their expectations for how things will change in the future. We also present the most prevalent challenges, concerns, and opportunities identified by participants (Table 3). A table summarizing all the responses related to perceived and anticipated impacts is provided in the Appendix (A3.2).

Table 3.3: *Perceived concerns, challenges, and opportunities regarding EV batteries across stakeholder groups*

Category	Frequent responses
Concerns & challenges	Safety (n=6) Supply chain constraints (n=5) Economics given the cost of transportation (n=3) Economics given battery design and chemistry (n=3) Unlicensed dismantlers processing EVs (n=3) Managing driver expectations regarding durability and EOL value (n=2) Lack of information for consumers, EOL processors, first responders (n=2) Unclear or patchwork regulation (n=2)
Opportunities	Environmental benefits of EVs (n=4) Create a closed loop system (n=3) Improve recycling technology and recovery rates (n=2) Develop domestic supply chains (n=2) Reusing/repurposing batteries to improve affordability of EVs and stationary storage (n=3) Growth in warehousing, distribution, logistics, and service sectors (n=2)

OEM network. According to participants, vehicle electrification has already fundamentally restructured the automotive industry (P22, P25, P26). It has created a significant impact on the workforce as OEMs look to hire engineers with different skill sets to design EVs, sales representatives at dealerships learn how to sell them, and technicians learn how to repair them. From a consumer perspective, vehicle ownership and maintenance will look substantially different for an EV compared to internal combustion engine (ICE) vehicle. EVs require less maintenance throughout the lifetime of the battery, but there could be a significant cost to replace the battery, and potentially even a cost to recycle it (although it is unlikely that consumers will be responsible for any recycling cost). While the net cost may be similar or even less for an EV, this represents a significant departure in expectations for consumers who have historically been paid for the scrap metal and battery of an EOL ICE vehicle. OEM and dealership representatives both expressed concern about how this would impact drivers (P22, P26), particularly lower-income drivers if they purchase a used EV and are then faced with the burden of replacing of the battery (P22).

One participant noted that EVs also require OEMs to rely more heavily on commodities with supply chains that are outside their control such as cobalt, nickel, lithium, and semiconductors (P25). This reliance has motivated an unprecedented focus on recycling by OEMs, at least for those represented in this study (P29). Looking towards the future, participants identified recycling and domestic production as mutually beneficial opportunities; production scrap and test batteries from domestic manufacturing provide feedstock for recyclers, while recycling will provide a growing source of supply for battery materials (P25, P26, P29). One participant also anticipated that the relationship between OEMs and the independent afterlife vehicle market could change if OEMs seek to control their out-of-warranty batteries at EOL; for example, they may negotiate with dismantlers to purchase batteries or pay for the collection cost (P29).

Independent afterlife vehicle market. The stakeholders from the auto dismantling industry who participated in this study (n=5) mainly work with ICE or hybrid vehicles and had not yet experienced a significant impact from battery EVs; however, several identified a need for the industry to adapt in the future (P2, P3, P5, P17). Their business model today is largely driven by revenue from parts that will not exist in EVs, and they will need to develop the capacity to process and store high-voltage LIBs safely (P3). It may also change their customer base, as dismantlers who process EVs could sell directly to battery repurposers, recyclers, or OEMs in the future. One small-scale dismantler expects that it will be difficult for smaller companies to remain viable due to the space and equipment required to handle EVs and because it will be more challenging to achieve the economies of scale that are needed to make transportation cost-effective (P7).

Several dismantlers pointed to unlicensed dismantling as their greatest concern and worried that any additional regulations placed on dismantlers would push more vehicles into an unregulated gray market (P1, P2, P7). “Unregulated gray market” describes individuals who dismantle vehicles and sell parts through online marketplaces such as Craigslist without complying with environmental protection regulations (California Department of Motor Vehicles, 2020). Unlicensed dismantling presents environmental and safety issues for all vehicles but is particularly undesirable in the case of EVs due to the safety hazards associated with processing high-voltage LIBs, and the difficulty of tracking and capturing these batteries for recycling. Several participants emphasized the fact that auto and scrap recycling are market-driven industries, and dismantlers only purchase vehicles if they think they can profitably resell the parts, so without a viable reuse, repurposing, or recycling option, there is a greater risk that EV batteries will be handled by unlicensed individuals (P7, P1).

Scrap recycling representatives did not report experiencing a significant impact to date from battery EVs (P13, P17). However, they do handle hybrid batteries, which present a challenge at small volumes because they are not economical to transport (P13). Participants anticipated a significant impact in the future which will require scrap recyclers to develop the capacity to process high-voltage batteries as more BEVs retire out of warranty (P13, P17). Meanwhile, the insurance auction representative did not perceive a significant impact to date and had not seen a drop or increase in sales that could be attributed to EVs (P16).

Reverse logistics: transportation, storage, sorting. Participants who work in collection and storage reported handling increased volumes and creating higher-skilled jobs due to vehicle electrification (P6, P12, P23), and anticipated exponential growth in the future as more EVs retire (P19). Participants from other industries also expected that the logistics sector would continue to grow and that the transportation network would become more efficient in the future (P21, P22, P24). In addition, companies that have historically serviced other products, including ICE vehicle parts and telecommunication tower batteries, are considering leveraging their existing networks to provide reverse logistics services for EVs (P9, P23, P24). However, in the near term, the burden of transportation may place smaller operations at a disadvantage without the capacity to aggregate larger volumes of LIBs (P7). One of the challenges mentioned by participants was efficiently storing and shipping EV batteries given the variation in pack design across different OEMs and models, which they hoped would decrease in the future (P6, P12).

Repurposing. The repurposing industry has not so much been *impacted* as *created* by vehicle electrification. However, the industry is currently constrained by the low volume of retiring EVs. As a participant from a repurposing company noted, “it’s actually a lot more difficult to get our hands on enough of these batteries than we had originally thought” (P15). While low volume is a challenge across all sectors, it is exacerbated for repurposers because each system must be made from homogenous batteries, so they need to acquire batteries from specific EV makes and models (P18).

Another challenge is battery diagnostics (i.e., estimating the battery’s remaining capacity). A preliminary estimate of pack-level SOH or mileage is sufficient to inform purchasing decisions, but more detailed data is needed during the repurposing process. Pack-level SOH estimates from the OEM BMS are accessible to dealership technicians when the battery is in the EV and can turn on (P18). Once the battery is removed from the vehicle, SOH data from the BMS is difficult to access, either because it is proprietary and only accessible to OEMs or because the data is housed in a controller onboard the vehicle and is separate from the pack. The repurposing companies who participated in this study are actively developing their own technology to work around this issue (P15, P18), but it increases the time and cost of repurposing. Other information about the EV’s history could also provide insight into its expected degradation and facilitate more efficient battery diagnostics. For example, charging patterns (e.g., level 2 vs. DC fast charging), driving patterns (e.g., local commutes vs. heavy highway usage), and climate (P15) are all relevant to battery aging.

A major barrier to repurposing is the mismatch in standards and certifications required in the automotive and stationary storage industries (P15). For example, UL1974 is a battery repurposing standard that has been adopted in fire codes and by the National Fire Protection Agency (NFPA), but, at the time of this writing, there are only two UL1974-certified repurposing facilities in the world. Another example is UL9540A, a fire testing standard for energy storage systems adopted by fire codes.

Although automotive batteries also undergo fire testing, the automotive industry uses different test protocols and data collection methods. Per the fire codes, EV batteries also need to have a UL9540A listing before being repurposed for stationary storage. Repurposers would have to shoulder this financial burden before going to market, further increasing the cost of repurposing and presenting a significant barrier to entry for smaller companies. Participants also noted that having access to prior certifications (e.g., SAE J2929, UL1642) would help assess stationary storage safety (P15; Table 4).

Repurposers expected that in the future, a higher percentage of batteries will be repurposed before recycling, and that larger volumes will enable more sophisticated and grid-connected repurposed systems (P15, P18). One participant anticipated that consumer confidence in reused batteries would increase in the future, which they viewed as an opportunity to improve accessibility of zero-emissions technology (P15).

Recycling. Today, the primary feedstock sources for battery recycling are production scrap from cell manufacturing, test EV batteries, and consumer electronics; however, in the future, participants expected the vast majority to be from EOL EVs. As EV technology evolves, two recyclers anticipated processing at the pack level to adapt to potential changes in OEM design (P10, P20). One has already developed the capacity to do so for damaged batteries (P28). Participants also anticipated automating the disassembly process once they operate at a higher throughput (P19, P20). In addition, recyclers anticipated that things will become “more fun and interesting” as batteries are retired out of warranty; different actors will be involved and battery shipments will be more heterogeneous (P28).

Discussion: Prominent Themes and Policy Implications

Access to Information.

Every stakeholder group needs information about the battery they are handling to identify its worth, where to send it, and how to process it (Table 3.4). Information about cathode chemistry enables sorters (or whoever removes the battery) to understand its material value and makes it easier for recyclers to sort LIBs into homogenous batches, which increases process efficiency. Meanwhile, quickly and reliably estimating SOH would support reuse and repurposing on multiple levels. Reducing the time required to screen and reconfigure the batteries would lower the cost of the process, and accurate estimates enable companies to provide reliable warranties. This is important to increase consumer confidence in used EVs and stationary storage (P9). Finally, if EOL LIBs are diagnosed in-field, they can be shipped directly to the appropriate destination, limiting unnecessary transportation.

Table 3.4: *Information about EOL LIBs needed by different stakeholder groups*

Stakeholder	Information needed
Auto dismantler	Battery chemistry and SOH to estimate remaining value and identify next use/potential buyers Condition of battery (damaged/undamaged) Battery position, size, and retrieval instructions Training to process high-voltage batteries Safety protocol for storage and shipping
Insurance auction	Condition of battery (damaged/undamaged) Battery chemistry and SOH
Scrap metal recycler	Battery chemistry to estimate value for recycling Information about battery position, size, and retrieval instructions to ensure batteries do not end up in a shredder
Repurposer	SOH at pack level to inform purchasing decisions (or mileage if SOH is unavailable) SOH at the module or cell level for repurposing process. Historical data from EV battery in first life (e.g., charging patterns) Certification information on the specific battery type (e.g., for SAE and UL standards) Access to BMS messaging and fault protocols
Dealer	SOH at pack level to identify next use Battery position, size, and retrieval instructions Safety protocol for storage and shipping to avoid fire hazard

Collection & logistics	Battery chemistry to identify which battery recycler to ship to and estimate value for recycling Dimensions for storage and transportation requirements If battery is damaged and requires additional safety measures
Battery recycling	Battery chemistry to estimate value for recycling Battery chemistry to sort batches for optimal processing efficiency If battery is damaged and requires additional safety measures

One strategy to increase access to LIB information is through labeling. In California, the California Air Resources Board requirements under the Advanced Clean Cars II regulation state that beginning in 2026, automakers must provide information via a physical label with a digital identifier, such as a QR code, that links to an online repository (CARB, 2022a). The label must include cathode chemistry, voltage, capacity, product alert statements/hazards, and composition. California's forthcoming regulations also require OEMs to provide a SOH estimate as a percentage of the battery's initial capacity on the vehicle dashboard and be accessible to mechanics when the battery is in the vehicle (CARB, 2022b). However, they do not require a SOH estimate to be readable once the LIB pack has been removed. The European Union proposes similar labeling requirements, but also includes the use of a "Battery Passport," a cloud-based technology installed in the EV that can track and store information about battery health, use, and final disposition (European Commission, 2020; GBA, n.d.).

As another policy example, China's Guidelines on New Energy Vehicle Recycling instruct vehicle producers to provide technical information on dismantling and repair as well as training to automakers, and establishes an online national information platform to monitor and track the production, sales, service, recycling and reuse of batteries (Gov.cn, n.d.). In the US, OEMs currently provide technical manuals with information about dismantling and repair (OEM Collision Repair

Roundtable, Inc., n.d.); however, there is no national platform tracking batteries throughout their life cycle.

Safety and Transportation

Parties that handle EV batteries must address two critical safety concerns: high-voltage electric shock and thermal runaway (Chen et al., 2022; Huo et al., 2017; Kong et al., 2018; National Transportation Safety Board, 2020). Safety is, therefore, foundational to sustainable EOL EV battery management and was mentioned by 13 participants. To minimize the risk of electric shock, stakeholders described strict safety protocols, including processing batteries in separated facilities with an insulated floor (P6, P12); using personal protective equipment (PPE) such as insulated tooling, arc flash helmets, balaclavas, and high voltage insulated gloves (P3, P6, P12); and having safety hooks onsite (P3, P6, P12). Participants also reported breaking down the busbars and modules to lower the voltage as the pack is dismantled (P6, P15). In addition, participants identified the following additional strategies to minimize the safety risk associated with EV batteries: (i) reduce the need for transportation by handling damaged batteries locally (P4); (ii) prioritize safety during battery design (P26); (iii) make information available for first responders (P25, P26); and (iv) design fire suppression systems for repurposed stationary storage systems (P18).

Meanwhile, transportation is central to the overall economics of EOL management and was discussed by 18 interviewees. Several larger companies have their own small fleet of vehicles (e.g., P6, P24), but there was a consensus that batteries are usually shipped through large third-party logistics companies. Participants described several strategies to reduce the burden of transportation. For example, one repurposing company found that due to shipping regulations, it was easier to receive batteries in pack form, at least at a lower volume (P18). Meanwhile, battery sorting facilities reported disassembling packs to the module level before shipping to remove unnecessary weight (P6, P14). Once the modules have been shredded and the critical minerals are converted to black mass, they are no longer classified as hazardous and are, therefore, easier to transport; consequently, developing strategic pretreatment locations is another mechanism to reduce transportation costs (P28).

To support the safe and efficient EOL management, accessible retrieval instructions, clear and consistent shipping regulations, and high-voltage safety training will be essential for technicians, recyclers, and first responders who have historically worked with ICE vehicles. At present, information about how to handle EV LIBs is provided through the NFPA and trade associations such as the Auto Recyclers Association (Auto Recyclers Association, 2020). It is important to note that there are also safety hazards associated with ICE vehicles, and indeed, grey literature reviewing safety data has found lower incidence of personal injury and fires with EV models compared to ICE counterparts (Clean Technica, 2018).

Circular Economy

The philosophy of creating a circular economy was a central theme across sectors. Stakeholders who work with EOL batteries saw vehicle electrification as an opportunity to increase recycling rates for LIBs in general (P6) and to set an example for creating closed-loop product systems (P19, P20). Meanwhile, OEM stakeholders considered recycling to be an integral part of their future EV supply chain (P25, P26, P29), which is consistent with the trend towards company-wide awareness of recycling as described by P29.

The interviews brought up several interesting implications of the circular economy paradigm shift that have not been explored in academic literature. First, it motivates more integration and collaboration along the value chain; for example, between recyclers and precursor producers to make sure the materials recovered will be suitable as inputs into the battery manufacturing process, as well as between auto OEMs and battery suppliers. Recent press releases announcing strategic partnerships between auto OEMs, battery suppliers, and recycling companies (e.g., Ohnsman, 2022; Weycamp, 2022) suggest this type of collaboration is already underway.

However, aspirations to close the loop do not seem to be manifesting in design for reuse, repurposing, or recycling, which is frequently discussed as an important solution by researchers and policymakers (e.g., Thompson et al., 2020; Rajaeifar et al., 2022; Nurdiawati & Agrawal, 2022; Gaines, 2014). Rather, the interviews indicate that repurposers and recyclers are adapting their processes for manufacturing; for example, by developing the capacity to process at the pack level, or innovating independent methods to diagnose SOH.

Another compelling implication is that recycling is increasingly considered as part of the supply chain, rather than a waste disposal mechanism (Alessia et al., 2021). If this is the case, OEMs will have the incentive to maintain control of batteries at EOL, which could create different relationships between OEMs and independent afterlife vehicle processors, or lead to novel ownership structures such as battery leasing (e.g., (Renault Group, n.d.)). At the same time, the value of EOL batteries as a material supply source could create competition between recycling and repurposing in the short term. Repurposing batteries as stationary storage will delay them from entering the recycling stream, which in turn delays their availability to be manufactured into new batteries. OEM- and recycling- stakeholders expressed that making nickel and cobalt available for recycling was a higher priority, since stationary storage batteries have lower energy density requirements and can therefore use lower-value cathode chemistries such as LFP.

To realize the environmental and security benefits of a domestic closed-loop system, North America will need to develop more precursor and cathode active material manufacturing capacity; otherwise, critical minerals that are recovered through recycling will be exported, processed abroad, then reimported for domestic cell assembly. While domestic cell and pack manufacturing capacity is rapidly growing, the vast majority of refining and precursor and cathode active material production takes place in Asia (P29). However, the landscape is rapidly evolving with support from federal policies. The US recently passed the Inflation Reduction Act, which requires EV OEMs to source a minimum percentage of battery components and material either domestically or from a specified list of countries (i.e., “friendshoring”) to be eligible for incentives (Inflation Reduction Act of 2022, 2022). One limitation is that there are no specific incentives for precursor material, leaving a possibility that material will still be exported and reimported at this step. The US Department of Energy is also seeking to address production gaps through strategic funding initiatives to support refining and component manufacturing (Walton, 2022).The EU has similar policies incentivizing the use of domestic and recycled materials, and identified cathode manufacturing as a strategic industry according to its criteria to promote important projects of common European interest (BASF Catalysts, n.d.; European Commission, 2021).

In addition to developing domestic midstream production capacity, North America and other industrial economies will also need to address potential leakage through the export of used vehicles and batteries. Unless there is a viable domestic reuse or recycling option, there is a risk that batteries with little remaining value will be sent to countries that do not have the capacity to manage them safely, posing an environmental and economic burden on the communities where these batteries end up (Kendall et al., 2023). In 2018, nearly four million used vehicles were legally exported from the US, EU, and Japan, with the US accounting for 800,000 (UNEP, 2020). In addition, each year there are as many as 3 to 4 million "missing" vehicles in Europe, some of which have likely been exported illegally (Tamma, 2018). In the US, many exported used vehicles are purchased at insurance auctions. The auction representative we spoke to (P16) characterized this as providing an affordable transportation solution for lower-income countries, where people repair the cars and keep them on the road far longer than is typical for the US. However, EVs are more complicated to repair and recycle, and exporting an EV with little remaining battery capacity effectively transfers the burden of disposal to the importing country (Kendall et al., 2023). This also means those materials would no longer be available to feed into a domestic circular economy system.

Finally, true circularity (i.e., supplying most or all new demand with recycled material) would require an eventual leveling-off of consumption to achieve parity between the volume of batteries that are retired and the level of material demand; even under unrealistically optimistic assumptions about collection and processing efficiency, the estimated maximum circularity potential for EV battery minerals is around 60% in 2040 if current trends in per-capita car ownership and battery size continue (J. Dunn et al., 2021). This points to the importance of including reduced consumption in discussions of LIB circularity, which, at present, have a limited focus on reuse and recycling (Remme & Jackson, 2023). Demand could be reduced through the adoption of smaller cars, and by pursuing less material-intensive strategies to meet the mobility needs of growing populations, for example public transit, active mobility, and car-sharing, in parallel with electrification (Riofrancos et al., 2023).

Economics of Collection and Material Recovery

A purely market-driven system is reliant on reuse, repurposing, and material recovery being profitable when accounting for the cost of collection and processing (Slattery et al., 2021; Wang et al., 2020; Lander et al., 2021). Without clear policy regarding the fate of EOL LIBs, there is a risk that they will be stranded or exported in the event that domestic reuse and recycling are not profitable; for example, in situations where transportation presents a greater burden (e.g., damaged batteries or batteries in remote locations), or due to evolutions in battery design towards lower-cobalt or cobalt-free cathode chemistries (i.e., LFP) that reduce the value of recycling. In these cases, a mechanism that assigns responsibility for the cost of collection and recycling may be necessary to avoid placing a burden on the consumer or smaller businesses in possession of an EOL battery.

The EU and China have both implemented producer responsibility policies to ensure batteries are collected and recycled. The Chinese Ministry of Industry and Information Technology released Guidelines for the Construction and Operation of New Energy Vehicle Power Battery Recycling Service Networks in 2019, which directs producers to establish collection and recycling service networks in areas where they sell EVs (SMM, 2019). The guidelines specify that battery producers, EV producers, and auto recyclers can jointly build and share networks. They also include requirements for collecting information; for example, by directing that the recovery service network keep records of the vehicle identification number and destination of each battery for three years. These requirements also apply to cascaded utilization producers, i.e., repurposers. Meanwhile, Europe's revised battery directive includes extended producer responsibility, which requires producers of automotive and industrial batteries to organize the collection of waste batteries at no cost to the consumer and without requiring the purchase of a new battery (European Commission, 2020).

Similarly, policy may be necessary to ensure that strategic materials are recovered regardless of their commodity value. For example, lithium has historically been left in slag rather than being recovered in usable form because it was not valuable enough to make the additional processing economical (J. B. Dunn et al., 2012). However, this is changing with increasing lithium prices, and recycled lithium carbonate is currently recovered in China (SMM, 2022). One strategy to guarantee the recovery of strategic materials is through minimum material recovery rates, which are included in the EU's Revised Battery Directive (European Commission, 2020). The EU's policy requires that 90% of cobalt and nickel, and 35% of lithium be recovered in 2025 and 95% of cobalt and nickel and 70% of lithium in 2030.

Conclusion

In this paper, we chart the EV EOL network by interviewing experts across vehicle and battery reuse and recycling sectors. The interviews indicate that market-driven reuse and recycling industries are developing without a comprehensive EOL policy in North America. Many EOL EVs in the United States are managed through existing channels that have historically processed ICE cars, including independent auto recyclers and dealerships within the OEM network. The safety and livelihoods of people working in these industries stand to be dramatically impacted by vehicle electrification, and their perspective is essential to identify the strengths and limitations of the existing system. In parallel, there is a growing cohort of new companies focusing on LIB reuse, repurposing, and recycling.

Stakeholders across this evolving ecosystem demonstrated a shared commitment to circularity in the LIB value chain and expected that recycling would be an important source of battery materials in the future. Challenges related to safety and the cost of transporting EOL batteries were also common themes across different sectors. However, there were also areas that were unique to different groups, particularly regarding challenges and concerns. Stakeholders in the independent afterlife vehicle market have a heightened concern about EOL EVs being handled by unlicensed parties and are skeptical of regulations that will increase the cost of operating. Repurposers, which are generally smaller startup companies, struggle with the cost of product certification and accessing information about the battery's remaining capacity. There is also a potential tension between the priorities of OEMs and independent companies who participate in reuse and repurposing industry. The former has an interest in maintaining control of their batteries, both to avoid any safety-related incidents and so they can keep the recycled material in their supply chain. This may put repurposing companies at a disadvantage if they are essentially competing for batteries, particularly considering policies that incentivize the use of recycled materials.

State and federal governments in the US and Canada are actively implementing policies that address number of the challenges and opportunities discussed during the interviews. For example, labeling requirements in California respond to the need for standardized information about LIB composition and condition (CARB, 2022a; CARB, 2022b). Strategic funding and incentive requirements in the US Inflation Reduction Act will support the domestic component manufacturing and encourage the use of recycled material in new products (Inflation Reduction Act of 2022, 2022). However, there is currently no mechanism to guarantee that LIBs are collected and recycled, nor is there a national tracking system that would provide more robust data on LIB management. Rather, at present, the system relies on the profitability of recovered materials or reused battery when accounting for the cost of collection and processing, creating a risk of stranded LIBs and/or wasted materials for battery packs that are lower-value or difficult to access.

This study provides a foundation of information about the different pathways for EOL EV LIBs. It is essentially a snapshot of the network in its early stages of development, representing diverse stakeholder perspectives to highlight qualitative barriers and opportunities. However, there are several limitations that point to important opportunities for future research. First, our study is focused on battery EV passenger cars, and does not consider LIBs from hybrids, heavy-duty vehicles, or micromobility. We also do not meaningfully investigate the implications of vehicle electrification for the independent repair network, which will be essential to understand as more batteries retire out of warranty. Finally, while we map out the potential pathways, we do not quantify them. Further study is needed to determine the volume of LIBs that are retired and handled through these different channels.

Dissertation Conclusion

In this dissertation, I analyzed lithium and battery manufacturing development through the lenses of energy justice and life cycle assessment, and explored the network of actors that handle end-of-life batteries. I used a mixed-methods approach, which enabled me to connect technical information with stakeholder experiences and identify research questions that are relevant to frontline communities. Taken together, these chapters reveal a rapidly developing landscape, characterized by individuals and institutions that have stated a clear intention to have a positive impact and create a circular economy for batteries. And at the same time, systemic forces and dynamics are at play which run the risk that the new energy system will look very much like the last in terms of who wins and loses, and in terms of creating new problems that future generations (me and beyond) will have to deal with.

Main Findings

Chapters 1 and 2 examined Lithium Valley, which should be a best-case scenario for lithium extraction. Direct lithium extraction (DLE) from geothermal brines has a smaller footprint than brine evaporation or hard rock mining, particularly in terms of land use. Furthermore, the development is in California, a state that has long considered itself a leader in environmental protection and socially progressive politics. Indeed, I found that the State of California and other stakeholders have made commendable strides in supporting environmental justice compared to business-as-usual developments. Notable initiatives include establishing the LVC, a public body with representation from CBOs and tribes; passing a “Lithium Tax” that directs revenue to be invested in frontline communities and the restoration of the Salton Sea; workforce development programs to train residents for anticipated jobs; and funding to support CBO-led outreach to facilitate broader public participation. California's environmental protection laws also require companies to prepare extensive environmental impact reports and provide opportunity for public comment, providing data about facilities and stakeholder perspectives that would likely be unavailable in other jurisdictions.

At the same time, challenges are arising that are consistent with critiques of green extractivism in other developments (e.g., Voskoboyni & Andreucci, 2022), including rigid state-led public participation processes, a lack of mechanisms to ensure accountability or incorporate community feedback, and the difficulty of providing straightforward information about the anticipated impacts of development. According to environmental justice literature, longer and more participatory processes are needed to build trust and create a shared vision for Lithium Valley, particularly considering the preexisting environmental burdens, social vulnerability, and history of marginalization. The fact that clean energy minerals such as lithium are urgently needed for climate change mitigation conflicts with the time needed for meaningful community engagement, a tension that is likely to arise in other developments.

Chapter 1 does not contribute original research regarding the environmental sustainability of DLE; rather, I aggregate information from existing data sources and discuss them in the context of stakeholder concerns. According to EIRs and available literature, DLE is not expected to have a significant impact on air quality, and the announced facilities do not exceed the industrial water allocation. However, DLE is expected to generate substantial volumes of solid waste, some of which will be hazardous. The geothermal production and injection wells must also be carefully sited and monitored to avoid triggering active faults. Furthermore, there are complex dynamics between environmental and socioeconomic factors; for example, water reallocation affects Salton Sea water levels, which would impact air quality and employment for farm workers.

The ultimate vision for Lithium Valley is to create a manufacturing hub, where the lithium is used to produce batteries locally using geothermal energy. In Chapter 2, I analyzed the local and global environmental implications of such a hub. I found that producing a cell in the geothermal hub reduces emissions by approximately 36% to a battery produced in the Southeast US, and 51% compared to a battery produced in China. The primary driver of reduced emissions is the use of geothermal energy for process heat and energy, followed by using DLE instead of market lithium from Australia and Chile. Reducing freight distance by locating manufacturing near the lithium resource has a limited impact on the overall carbon footprint.

I also estimated the water and energy demand for a geothermal battery hub and identified potential drivers of waste. According to these calculations, the current water allocation could support approximately 106 GWh of CAM and cell production per year, which would use roughly 83% of the announced LiOH production capacity (34 kilotons). Expanding lithium extraction beyond the announced facilities will either limit the potential for manufacturing or require water to be reallocated from other sources, namely agriculture (though this could be mitigated through improved water efficiency measures). A hub with a capacity of 106 GWh per year would produce an estimated 636 kilotons of waste per year, of which approximately 20% is expected to be classified as hazardous waste and require specialized treatment.

These results suggest that collocating battery manufacturing with a renewable resource has a greater impact on the life cycle greenhouse gas emissions than collocating near a lithium resource, although there may be economic benefits associated with collocating near mineral extraction, particularly in terms of job creation. The Salton Sea region could therefore be an attractive location for manufacturing even without lithium extraction, particularly if new geothermal facilities are designed to produce process heat in addition to electricity. However, new developments should be considered within a water budget based on constraints, competing uses, and the informed participation of local communities.

In Chapter 3, I explored the growing network that handles end-of-life EV batteries. The network includes established industries that historically handled internal combustion engine (ICE) cars, such as automakers, car dealerships, auto dismantlers, and scrap metal recyclers, as well as newer companies developing technology to reuse or recycle LIBs. At present, auto and scrap recyclers mainly handle ICE cars and hybrids, battery recyclers are mainly processing production scrap, and repurposers are still identifying channels to procure a steady stream of used batteries.

However, things will change as more EVs start retiring out of warranty. For example, stakeholders in automotive industries will need to learn how to process high-voltage batteries, and repurposers expect to build larger and more sophisticated systems as more batteries become available. Several prominent themes emerged during interviews, including safety, storage and transportation. Every stakeholder category expressed a need for better information about the batteries they are handling, which would make the system function more efficiently.

The battery end-of-life network is growing rapidly, supported by recent federal legislation, which counters a pervasive popular narrative that batteries cannot be recycled or are recycled at a very low rate. At the same time, it is a market-driven system, meaning reuse and recycling must be profitable considering the cost of shipping and processing. This may present a challenge for batteries with lower-value materials, or for damaged batteries that are extremely costly to ship. At present, no party is required to collect and handle these batteries if they are out of warranty. Another gap is exports; a high volume of used vehicles are exported from the US, and without controls or a robust tracking system, it is difficult to know where batteries will end up. If used EVs or batteries are exported, the critical minerals will be lost from the domestic system, and they will likely create a burden in importing countries that do not have the infrastructure to recycle them.

Reflections on Research Process and Contributions

This dissertation is highly interdisciplinary. It draws from fields spanning industrial ecology, civil and chemical engineering, environmental science, geography, and science and technology studies (STS), and connects them with stakeholder perspectives that are outside academia altogether. As a researcher, navigating the norms of such distinct fields was an interesting and challenging experience. Engineering and industrial ecology articles are typically written in the third person to indicate neutrality, whereas critical social science fields encourage researchers to address how their identity influences bias and privilege related to their work. My exposure to feminist science taught me it would irresponsible *not* to address situations of injustice through my work, and at the same time, my experience in quantitative fields makes me wary of blurring the lines between scholarship and activism. I did my best to strike a balance.

Applying such an interdisciplinary approach has tradeoffs. For the most part, I believe it enriched my analysis and facilitated a more nuanced understanding of the EV battery life cycle that will be relevant to policymakers, industry, civil society organizations, and researchers alike. At the same time, it arguably limits the depth of my contribution to specific academic fields: incorporating a technical focus limited my ability to conduct a more critical social science analysis of clean energy supply chains, while the qualitative dimensions make it difficult to produce easily interpretable numbers to compare with other quantitative analyses.

In Chapter 1, incorporating insights from environmental justice scholarship encouraged me to include historical context and issues of power and access in my analysis of Lithium Valley. Including these dimensions yielded a much more comprehensive understanding of the development than would be possible if it were limited to quantifiable analyses of GHG emissions and financial cost. Furthermore, seeking out community perspectives informs research that will address priority issues for frontline communities, rather than relying on questions previously identified by academic research or policymakers. For example, solid waste was a high priority concern for community members and advocacy organizations, though it is rarely included in LCAs of lithium or batteries. Following this finding, I included pretreatment and waste streams in my quantitative analysis of DLE and battery manufacturing in Chapter 2, which had an important influence on the results. My understanding of the socioenvironmental dynamics in Lithium Valley also led me to evaluate manufacturing considering available resource constraints (i.e., within the existing water allocation).

In Chapter 3, seeking out the perspectives of those directly involved in end-of-life management elucidates the pathways EV batteries may follow when they are retired from a vehicle. These insights will allow for more accurate estimates of future material flows, costs, and environmental impacts. Most existing literature has either relied on simplified assumptions or ignored the steps between vehicle retirement and recycling altogether. Other MFAs have used expert elicitation to inform their analysis; however, they often do not explain their methods for recruiting participants, their interview process, or their protocol for analyzing qualitative data. By including detailed and systematic qualitative methods about how I discovered practical information, I provide a transparent and replicable example that others can critique or build on. Seeking out stakeholder perspectives also informs more nuanced policy recommendations; for example, by highlighting the importance of safety training and alleviating the burden of transportation for small operations. However, I did not quantify the volumes of batteries flowing through each channel.

There are many opportunities to build on this dissertation beyond what I recommended in the chapters. From a social science perspective, it would be interesting to analyze whether the role of lithium in climate mitigation makes the supply chain more or less sustainable compared to other minerals. During this process, I've suspected both; on one hand, projects led by billion-dollar corporations seem to rush ahead and with full government support. On the other hand, developers and policymakers seem compelled to align projects with values of equity and sustainability, at least rhetorically, and lithium receives a level of media attention that I think is unprecedented for other minerals. A related question is how consumer attitudes towards supply chain resilience, sustainability, and human rights have changed due to the COVID-19 pandemic and social justice movements, and to what extent this influences companies' practices. Finally, I think it would be a fascinating STS study to analyze how scientists' personal values about climate change and sustainability influence how they conduct and report research about the environmental impacts of clean energy minerals.

Takeaways for Clean Energy Supply Chains

As transportation and energy systems shift towards cleaner, material-intensive technologies, researchers must adapt to analyze impacts beyond greenhouse gas emissions. Local considerations must be balanced with global priorities to inform the sustainable sourcing and implementation of clean technology solutions, without sacrificing the urgency of climate change mitigation.

Chapters 2 and 3 translate to recommendations about environmental sustainability that are relatively straightforward, if not easy. To summarize them: minimize the GHG footprint of battery production by powering manufacturing with low-carbon energy sources, which is more impactful than reducing shipping distances. Invest in research and infrastructure to minimize solid waste and recycle byproducts and production scrap. Support reuse and recycling by defining responsibility for end-of-life batteries, implementing measures to track them and make information more widely accessible, and develop training for workers that historically handled ICE cars so that EV batteries are handled safely, and identify ways to reduce the burden of storage and transportation.

The recommendations surrounding mineral extraction and environmental justice are more complex. The first Lithium Valley chapter highlights two fundamental challenges that may come to define environmental justice for clean energy supply chains: the tension of balancing urgency with inclusivity and meaningful participation, and the difficulty of providing information about novel technologies in the face of uncertainty. Another key takeaway is that the regional and historical context fundamentally shapes local stakeholders' perspectives about any new industry, including lithium. Put simply, no extractive industry at this point in history should expect communities to take promises of jobs and other benefits at face value, particularly in areas that have already experienced decades or even centuries of environmental burden.

To navigate these tensions, I recommend policymakers and industry proactively establish plans for monitoring environmental impacts and accountability measures to ensure the benefits promised during development accrue to local communities. Perhaps most important is the need to budget resources upfront for *dialogue-based* community engagement, with sufficient time and clear mechanisms for the output of these engagements to shape the development. Researchers can also play a key role by partnering with community-based organizations, continuing to study environmental impacts and public health, and evaluating social and economic impacts such as employment, infrastructure investment, and cost of living. For researchers in quantitative disciplines, these findings highlight the importance of including local impacts in sustainability analyses, particularly waste, water availability, and public health, and evaluating potential environmental impacts considering place-specific factors.

The recommendations identified here will require more resources in terms of time, money, and people. There is a real risk that the added cost will render responsible development infeasible because companies will not be able to compete with lower-cost extraction pathways. However, I worry that the risk of not investing in these measures will be even greater. There is increasing evidence that a new model for mineral supply chains is not merely desirable from an ethical perspective, but rather, it is crucial to the success of the energy transition. The International Roundtable on Materials Criticality lists “Reputational damage due to environmental or social impacts in the company’s value chain” as one of the three types of risk associated with critical materials (Irtc 2020, p. 14), while the International

Energy Agency (2021) lists "growing scrutiny of environmental and social performance" as one of five "vulnerabilities that may increase the possibility of market tightness and greater price volatility," thus threatening the speed of the clean energy transition (pp.11-12).

And indeed, lithium extraction is being protested all over the world. Proposed and operating lithium mines face resistance in Chile due to disputes over water use and Indigenous rights, and in Portugal, where a municipality filed a lawsuit to stop the development of open-pit lithium mines amidst "an ongoing corruption scandal related to 'green' energy deals" (*Reuters* 2023). In Nevada, the Thacker Pass project has faced opposition and lawsuits over the local ecological impacts, the destruction of sacred Indigenous land, and perceived inadequacies in the environmental review and tribal consultation processes (Angueira, 2023). Without changing how we develop new supply chains, we risk moving forward with a transition that perpetuates inequality and injustice or undermining the clean energy transition altogether.

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Introduction

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Chapter 2

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Appendix

A1. Chapter 1

A1.1. Codebook for transcript analysis

<u>Water</u>

- Initial coding criteria for transcripts: line contained “Water” or “gallons” or “acre feet”
- Unit of analysis= one line of text
- Exclude: water used metaphorically (e.g. “and actually when you look at the entire loan program amounts, they actually are above water because some of these projects have been so successful”
- Secondary coding::

Subcategory	Code	Use cases	Examples	#
Policy and management	w__pm_regulation	References to regional water regulations including agencies, policies, and permit requirements	“The **Water** Board has several permits that are typically required for geothermal projects” “We also oversee the injection projects with a separate permit where we oversee where the **water** is going”	40
Policy and management	w_pm_managemen t	management by water utility, water allocation rights, purchase and transfers of water rights, distribution system	“The other canal that is also basically used to deliver **water** to the farming community and the cities that we have to serve” “The **water** rights themselves become kind of a stable point that because of our seniority in the water rights, it is a safe harbor per se”	85
Regional context	w_rc_scarcity	References to regional water scarcity or water quality issues	“**Water** sources in the middle of this desert are extremely limited.” “In a community, in a region that is already plagued with limited **water**, it is a concern for a lot of people the amount of **water** that will be used.”	16
Regional context	w_rc_SS	Salton sea water levels, composition	“I mean, if you took a cup of water at the Salton Sea, a quarter to a third of it would be minerals.” “In the process of injecting the	16

			brine back, where does it go, and does any of it stay in the Salton Sea water or enter the aquifer?	
Consumption	w_c_consumption: volume	Volume of water consumed by process	“How much **water** is needed in the lithium refinement process?” “But a ballpark, maybe of 15,000 **acre feet** a year for our existing facilities”	31
Consumption	w_c_consumption: source	Source and type of water consumed by lithium extraction or geothermal processes	“I think there's been a misunderstanding of where the **water** source for the geothermals come from or process water, and it's not the Salton Sea. It is coming from the Imperial Irrigation District.	10
Consumption	w_c_comparison	Discussing alternative production methods, comparing DLE to alternative production methods	“It’s the lowest unit **water** user of any lithium production technique” “Open pit hard rock mining…requires a huge amount of **water**, a huge physical footprint, and really reshapes the environment as gigantic tracts of land or altered physically and ecologically”	41
Consumption	w_c_conservation	Efforts on behalf of industry to reduce water consumption	“We’re targeting a minimum of 90% less water” “And the key for us is to look at how many times we can reuse a gallon of water”	25
Other	w__o_process	Explaining the process of geothermal energy production and/or DLE, including the volume of brine that is processed	“After the steam turns the turbine, it's condensed back into **water**, and it goes to the cooling tower”	26
Other	w_o_other	Not directly related to DLE or Salton Sea	“The Geysers up in the Santa Rosa Healdsburg area, they were having trouble with **water** use at some point”	34

Employment

- Keyword search for transcripts: employ OR employment OR jobs OR workforce OR training OR unemployment
- Unit of analysis= one line of text
- Exclude:
    - “Did a good job” “completed that job”
    - “My previous job was”
    - Employment related to industries outside region, i.e. not geothermal, lithium, battery production, or other ancillary employment (e.g. “the automotive industry employs over…”)
- Secondary coding:

Code	Use cases	Examples	#
e_workforce	Workforce needs of industry, existing local workforce	“The other issue we were asked to kind of touch on real quick, kind of our workforce needs”	74
e_workdev	Workforce development; training programs including apprenticeships and community college curriculum	“I think we are definitely going to need some type of vocational training to prepare for those operations”	88
e_job creation	Quantity of jobs that will be created by lithium and ancillary industries need for jobs in region Generic mentions of “jobs”	“when this is fully realized, our development is fully realized, we're going to have a very significant impact on the **job** position of Imperial County” “So jobs, you know, in our project alone, fully built out, is sort of close to 2,000 jobs.”	65
E_job quality	Type and quality of jobs that will be created by industry, including permanent vs. temporary, safety, union representation	“whether they're union **jobs** or non - union jobs, that they are local jobs and there are good jobs.” “I would be very interested to know what types of **jobs** have been offered at facilities that were constructed and like local areas. And generally, what the average wage was maybe, and like the quality of the jobs”	43
e_history	Historical promises of employment that have not been realized	“I’ve lived here the majority of my life, so I' ve seen it, both growing up here but also in the professional field, that we have a lot of development always shows up with the promise of creating **jobs** and it tends to be sort of the negotiating and the wow factor in these	19

		communities” “And that came in and it turns out there’s not a whole lot of **jobs** that , once the construction happens.”	

Health

- Keyword search for transcripts: Health OR healthcare OR illness OR disease
- Unit of analysis= one line of text
- Exclude: related to COVID protocols
- Secondary coding::

Code	Use cases	Examples	#
Health_existing	Existing public health issues, ongoing efforts to address the public health crisis in the region	“I can name at least three of the main huge issues here in the region, one being public **health**, we’re talking about, you know, in correlation to the Salton Sea, the economy, and the environment.”	15
Health impact	Potential impact on health	“I wanted to highlight that environmental impacts can sometimes be seen from habitat, wildlife, or just interaction with the environment, but I would recommend that we also highlight public **health**”	13
health_protect	Importance of protecting public health *in the context of new developments*, processes established to protect public health such as permits and regulatory oversight	“There are many job opportunities that go in to assuring that our water, that our air, that our land, and that the public **health** is protected. Because when we don’t protect all those areas, and many more that I’m certainly not mentioning, that’s where, you know, we create a lack of balance.”	18
health_improve	Potential for lithium extraction to improve health, for example through supporting the health care system	“And we want to support the development of that in a way that's going to lift up under resourced communities in California and restore the land of the **health** of the region along the way.”	9
health_other	Title of organizations that focus on public health Health benefits of ZEVs	“The goal of these standards is to reduce vehicle-based carbon dioxide emissions that contribute to climate change, and to reduce the vehicle pollutants like NOx and particulate matter that degrade public **health**.”	5

Infrastructure

- Keyword search for transcripts: infrastructure OR rail OR broadband OR road
- Unit of analysis= one line of text
- Exclude:
    - “Down the road” metaphorically
    - “High road” metaphorically
    - Road used to name locations
    - Infrastructure or road refer to ZEV programs (e.g., EV charging infrastructure, on-road emissions)
- Secondary coding::

Code	Use cases	Examples	#
infra_industry	Industry’s existing access to infrastructure and infrastructure needs	“One of the **infrastructure** needs would be rail access.”	57
infra_supply	Infrastructure to develop more of the supply chain (e.g., cathode manufacturing)	“And what I would add is sections on the **infrastructure** needs for the building out of the supply chain”	7
infra_community	Community infrastructure needs and potential benefit	“especially on that **infrastructure** side , right, the need for roads, for broadband. Those have been needs that our community has been uplifting for many, many years.”	27
infra_other	Discussions of financing opportunities related to infrastructure	“Aligning with the state can be very, very helpful at, you know, getting designated as a major **infrastructure** project.”	8

<u>Ecology</u>

- Keywords for transcript search: Ecosystem, habitat, conservation, playa, restoration, species
- Exclude:
    - Ecosystem referring to supply chain actors
    - Species referring to extraction process (“removing the sodium calcium potassium species that we do not want”)
    - Conservation related to water conservation practices

Code	Use cases	Examples	#

eco_restoration	Ongoing efforts to restore, revitalize Salton Sea	“The SSMP team is focused on the following goals; implementation of the SSMPs phase 1, 10-year plan, which aims to improve conditions around the sea by constructing approximately 30,000 acres of projects to suppress dust from exposed [indiscernible] lakebed and create **habitat** for fish and birds.”	48
eco_restoration_complement*	Potential for lithium and geothermal industries to contribute to ongoing restoration efforts, e.g. through revenue or royalty payments, or restoration land on their property Importance of aligning and not interfering with ongoing restoration efforts	“How does new development positively, how can we contribute to Salton Sea, you know, **restoration**” “making sure that what is happening is consistent with the **restoration** efforts at the Salton Sea, both to benefit the community to minimize air quality impacts and to provide **habitat** for the migratory birds and the fish that are remaining in that area.”	30
eco_oversight	Describing state-led processes such as permitting or regulation designed to protect ecology, agencies tasked with permitting	“The Department of Fish and Wildlife may have permits required if there are states for endangered **species** on the site”	22
eco_impact_other	Impact of lithium extraction on ecology in Chile	“And you could imagine the impact on the groundwater or the land subsistence, the destruction, really, of the desert ecosystem as local residents and farmer are getting less and less access to water.”	4
eco_other	Personal history of speaker related to conservation Restoration or ecology regarding other projects Descriptions of Salton Sea ecosystem Ecosystems discussed in the abstract	“the water and the shore and the environment around with the birds and the **habitat** and everything is very near and dear to us” “That possibility of the right for communities to say no, or if certain landscapes or **ecosystems** being designated too vulnerable to weather extraction, needs to always be on the table.”	9

*Additional code level applied to texted already coded as eco_restoration

Waste

- Keyword search for transcripts: waste, byproduct

- Unit of analysis= one line of text
- Exclude:
    - Not related to physical waste (e.g. “I have nothing to waste”)
- Secondary coding::

Code	Use cases	Examples	#
Waste stream	Question or discussion about waste stream from geothermal/DLE process, management of waste stream	“What are your **waste** streams, specifically waste streams related to the extraction of lithium from the brine?”	23
Waste stream_min	Efforts to minimize solid waste References to minimal waste	“Our lithium recovery technology keeps the dissolved minerals suspended in the brine after the lithium is recovered so the brine can be safely reinjected back into the reservoir to minimize solid **waste**.” “There's very little solid **waste** that we would produce.”	16
waste_permit	Agencies and regulations that oversee waste, hazardous material	“So, there are a lot of agencies involved in permitting a power plant; Imperial County planting and developments services, public works, if you need a grading plan, for example, to move the dirt, environmental health, Department of Toxic Substances Control regulates hazardous **waste**, hazardous materials.”	3
waste_other	Waste or byproducts from alternative processes Battery waste streams as a source of lithium	“The idea of an open cut kit mine or, you know, a salar or evaporation ponds or waste products”	13

Air

- Keyword search for transcripts: Air, dust, particulate matter, pm, NOx, SOx, ozone
- Unit of analysis= one line of text
- Exclude:
    - Describing a process unrelated to geothermal/lithium extraction in the region (e.g. “at Mammoth Lakes...they can use what’s called air cooling”)
    - Referencing air conditioning
    - PM referencing time of day
    - Used metaphorically (e.g. “clearing the air”)
- Secondary coding::

Code	Use cases	Examples	#
air_existing	Existing air quality issues, ongoing efforts to suppress dust and improve air quality	"everyone knows that there's enormous air quality challenges" "Our current program activities include construction of the Species Conservation Habitat Project at the southern end of the sea consisting of approximately 4100 acres of habitat ponds, supporting fish and birds and providing dust suppression.	16
air_permit	Agencies and regulations that oversee local air quality Permitting requirements	"There are also noise, air quality and traffic modeling studies that are conducted"	27
air_impact	Questions or discussions about air emissions from geothermal/DLE	"clarify if there are any like potential impacts to the Salton Sea, or air quality, or the environment, those types of issues."	6
air_benefit	Positive impact of building facilities on exposed playa to mitigate dust	"So, this master plan is a big deal for Imperial County because wherever anybody decides to build their plant, they're going to eliminate that dust and air pollution issue."	2
air_other	Air emissions from alternative processes Statewide air quality impacts and policies related to zero emissions vehicles	"California ZEV policies are based on climate change and air quality standards"	12

Seismicity

- Keyword search for transcripts:
- Unit of analysis= one line of text
- Secondary coding::

Code	Use cases	Examples	#
seism_background	Explaining presence of geothermal energy in the area due to tectonic activity	"So, why do we have these areas that are high heat like Imperial County? Well, it's all driven by what's called plate tectonics."	6
seism_impact	Questions about the potential impact of	"But there are concerns about the seismic activity, about how much of disruption occurs in the	3

	geothermal and/or lithium extraction on seismicity in the region	siphoning or the production whether it's for the energy and whichever way it occurs."	
seism_mitigate	Monitoring plans in place, questions about safeguards against seismic events	"And all of the projects in Imperial County require subsidence and seismic monitoring programs."	3

Climate

- Exclude:
    - "Climate" referring to non-environmental climate ("jobs climate," "create a climate for dialogue")
    - Name of company ("Oxy Low Carbon Ventures")
    - "Carbon" referring to graphite as a battery material

Code	Use cases	Examples	#
climate_DLE emissions	Greenhouse gas emissions of DLE	"With lithium, I think there's going to be a concern with some unique resources, particularly air quality, traffic, and utilities, as well as greenhouse gas emissions."	1
climate_DLE_sustainable	Comparing carbon footprint of DLE to alternative lithium production methods Reduced carbon footprint through collocation	"And what we see is the smallest carbon footprint of any lithium production technique."	12
Climate_mitigation	Policies and goals regarding climate mitigation, renewable energy, zero emissions vehicles	"These efforts, in addition to many renewable energy goals and greenhouse gas reduction requirements being implemented around the world, are driving the increased demand for lithium."	28
climate_impact	Impact of global climate change and status of global climate Adaptation and resiliency to climate change impacts	"How can this benefit the community at large? Especially with climate change exacerbating the cost of cooling off their homes"	6

climate_other	Carbon emissions, offsets, or demand in other industries	"We managed to negotiate that deal which that makes CO2 free cement" "The first actual wells drilled in the county were for carbon dioxide for dry ice"	2

Emergency

Code	Use cases	Examples	
emergency_critical	Emergency related to reliance on imports for critical materials	"And the second, in 2020 declaring a national emergency in response to US reliance on other countries for sourcing those critical minerals."	
emergency_SS	Ecological crisis of Salton Sea	"It's oncoming ecological disaster."	

- Exclude:
    - Related to COVID-19 protocols

S1.2. Community Meeting Questions

Meeting 1: LCJA Junta Comunitaria, 7/20/2021

Event details:

- *Format*: Virtual meeting
- *Attendance*: 31 Participants
- *Organizer(s)*: Leadership Counsel for Justice and Accountability, residents of Eastern Coachella Valley
- *Purpose*: Provide a space for community members to ask questions to two LVC commissioners that represented the local community and an environmental organization.
- *Methods*: Researcher recorded a list of questions that were asked by the community and verified the list with notes shared by the event organizers.

Questions:

- ¿Qué se está haciendo para informar a más residentes? ¿Qué pasará en el Este del Valle debido a la extracción de litio? *What is being done to inform more residents? What will happen in the ECV due to Lithium Extraction?*
- ¿Cómo están involucrando a la comunidad? ¿Cuáles son los impactos a la comunidad? *How are you getting the community involved? What are the impacts to the community*

- ¿Qué impacto ambiental tendrá la extracción de litio, y cómo afectará la calidad de salud en las comunidades que lo rodean ya que estas comunidades padecen de muchas enfermedades respiratorias? *What environmental impacts will lithium extraction have, how will it affect health quality in the adjacent community which already suffers from many respiratory illnesses*
- ¿Cómo puede afectar la extracción de litio a la falla de San Andreas, es posible que la haga más sensible? *How can lithium extraction impact the San Andreas fault, is it possible for it to be more sensitive?*
- ¿Cuál agencia estatal será responsable de las acciones relacionadas con la extracción de litio? *What state agency will be responsible for the actions related to lithium extraction?*
- ¿Qué cantidad de litio será extraída? ¿Esta cantidad estará regulada por el estado? ¿Cuál es la cantidad máxima que se puede extraer? *What quantity of lithium will be extracted? Is this quantity regulated by the state? What is the maximum amount that can be extracted?*
- ¿Qué agua será usada para extraer el litio, será agua limpia o agua del Salton Sea? ¿Cuántos galones de agua se necesitan para extraer una tonelada de litio? ¿Habrá escurrimiento de agua durante el proceso? *What water will be used for lithium extraction, will it be clean water or water from the Salton Sea? How many gallons of water is necessary for extracting a ton of lithium? Will there be running water during the process?*
- ¿Cómo afectará la estructura de la comunidad (la nivelación de la tierra) la extracción de litio? *How will lithium mining affect the community structure (land leveling)?*
- ¿Los acuíferos proveerán la agua requerida para la extracción considerando la sequía? ¿El agua que se use para extraer litio será reciclada, reciclar el 1% no es suficiente debido a la escasez de agua en la región esto es importante? *Will the aquifers provide the water required for extraction considering the drought? Will the water used to extract lithium be recycled, recycling 1% is not enough due to the scarcity of water in the region, this is important.*
- ¿El proceso de extraer litio consume una cantidad extrema de agua. Sabiendo que vivimos en un lugar donde no hay mucha agua y la agua que si tenemos se está usando para la agricultura, como van a manejar esto para las minas? Como se van asegurar que nuestra agua de la comunidad no va ser perjudicada? *The process of extracting lithium consumes an extreme amount of water. Knowing that we live in a place where there is not much water and the water that we do have is being used for agriculture, how are they going to handle this for the mines? How will you ensure that our community water will not be harmed?*

  <u>Comments</u>

- La comisión debería de producir otra analogía para representar una imagen de la cantidad de litio extraída para aquellos que no pueden imaginar exactamente cuánto litio es, por ejemplo, 28 mil toneladas de litio. *The commission should produce an analogy to represent an image of the amount of lithium extracted for those that are unsure about the size of, for example, 28 thousand tons of lithium*
- Le pedimos que se produzca material que sea accesible y entendible para el público y que haya más oportunidades de alcance comunitario para hacer preguntas. *We ask that you create material that is*

accessible and easily understood by the public and that there are more opportunities to do community engagement and space to make questions.

- Se les invita a la comunidad de Salton City para que informen más a la comunidad y aboguen por ellos. Estas comunidades necesitan mucha atención. Queremos ver una unión entre los condados de Riverside e Imperial para responder a preocupaciones de la comunidad. *We invite you out to Salton City so that you inform the community and advocate for them. This community needs a lot of attention. We want to see unity between the two counties Riverside and Imperial to respond to the community's concerns.*
- Atraer más atención a la ingeniería para los jóvenes de la comunidad para ser parte de las soluciones. *Bring more attention to engineering for youth at Salton sea communities to be a part of solutions.*
- Como miembros de la comunidad no siempre pueden unirse a juntas para informarse sobre lo que está sucediendo, dio un comentario que por favor se reúnan tal vez como cada 3 meses, como representantes de la comunidad, para comunicar información sobre el proceso de la extracción de litio y que más se requiere para abogar para la comunidad. *Community members cannot always join meetings to find out what is happening, please meet maybe every 3 months, as community representatives, to communicate information about the lithium extraction process and what else is required to advocate for the community*
- También hay un problema de discriminacion y poder, hemos intentado tener eventos y proveer acceso a amenidades pero las personas, o familias con poder no lo permiten, es comparable con una mafia (aunque la mafia es más serio).*There is also a problem of discrimination and power, we have tried to have events and provide access to amenities but people, or families with power do not allow it, it is comparable to a mafia (although the mafia is more serious).*

Meeting 2: LCJA Regional Convening, 9/25/2021

The in-person meeting was a regional convening to generally discuss environmental justice issues in the region and was attended by 16 residents from the community of North Shore. There was one session devoted to lithium extraction. During this session, the researcher presented a basic overview of lithium extraction, then asked the participants what they would like to know about the process and recorded a list of their questions.

Meeting Details

- *Format*: Virtual meeting
- *Attendance*:
- *Organizer(s)*: Leadership Counsel for Justice and Accountability, residents of Eastern Coachella Valley
- *Purpose*: Provide a space for community members to ask questions to two LVC commissioners that represented the local community and an environmental organization.
- *Methods*: Researcher recorded a list of questions that were asked by the community and verified the list with notes shared by the event organizers.

Questions

- How will the development affect public health? (group consensus that health was the top priority)
  - What will be the impact considering all the public health crises that already exist?
  - How will they record the problems that already exist?
- How will the community benefit? (consensus as second priority)
- This will produce many batteries and is a valuable resource that will generate a lot of money. How will that money be spent? How will revenue be reinvested in the community?
- What will be the quality of jobs? Will they be safe?
- Will undocumented residents be eligble for opportunities?
- Other projects have said they would generate employment but the jobs don't really get to the community, especially because many young people are undocumented and not eligible.
- What infrastructure will be built?
- This will raise property values. How will it affect the cost of living for residents?
- How will the community be impacted if the area is designated as an Industrial Zone?
- How will waste be managed? What happens with other minerals and how will they affect public health?
- Request more information about the properties of lithium and how lithium affects public health
- Why is there lithium here?
- Does the lithium recharge when the brine is reinjected into the deposit?
- Since when has there been interest in lithium? (answered)
- How is this related to the plates? Could the reinjection affect the fault? Pointed out that there have been more earthquakes recently
- Who are the companies involved and what is their history?
- What voice does the community have?
- Comment that the community realistically cannot say yes or no if they want the development or not because there is too much money involved, but they can negotiate for benefits
- What would an emergency look like? What would be the worst-case scenario and what will be the plan to respond?

Meeting #3: LVC Community Forum, 11/15/2021

Meeting details:

- *Format*: Virtual webinar with in-person live stream at four locations in Riverside and Imperial Counties
- *Attendance*:
- *Organizer(s)*: Lithium Valley Commission
- *Purpose*: As stated in the meeting notice, the forum was held "to provide an overview about and introduction to the Lithium Valley Commission and the concept of the Lithium Valley and...to engage the community directly and encourage public participation in the efforts of the Lithium Valley Commission" (California Energy Commission n.d.).

- *Methods*: Questions are aggregated from meeting transcript and chat, which were published online (LVC_ Nov Community Forum Chat and Q&A...)

Questions:

- “One thing that I have seen, so I have this question, the question is, you talk about the potential for the economic: Has there been a comprehensive economic study that will give us the definitives based on solid economic methodologies of how much income will be produced by lithium extraction with geothermal and derivatives or supply- side chain reactions and other investments that could be made? And what is the window in that time of that development?I know the industry, in our meetings, have stated maybe 10 , 15 years. So, I think, is there such a comprehensive economic study? Because the community can ask, but if we don’ t have a basis of how to ask, it’ s just a blind ask. We want to make informed, educated, studied requests to improve our community from the ground up. So that's my first question.”
- “My question is in regards to the talk about supply chain, the possibility of supply chain being part of the economic system here with the possible lithium production. And my concern is with the companies, we currently have three companies here but others might arise if it’ s feasible, and my concern comes from is there any conversation tied into possible incentives, subsidies, or tax breaks, that these companies kind of hold the line or tow the line of not starting here and then exporting jobs to (indiscernible) and Mexicali and pay somebody, you know, $ 10 . 00 a day, and then we end up losing here and still have to deal with our environmental burdens.”
- So my question to you is -- in researching some of the Lithium Valley, and in the South America lithium valley there, which is called the Triangle, in Chile and Bolivia, and also in other parts where they are doing the lithium, there are like -- some of the negative impacts have included contamination of soil, contamination of water affecting some of the cattle. I’ m just wondering if/ how we are going to be able to address that? I know that there’ s going to be an environmental impact study and we will have the opportunity for the scoping. But since this is completely new to us, we won’ t really know like - or do you have an idea when we will start seeing some of those negative impacts in our community? And my second question to you, to the Lithium Valley Commission, is maybe it’ s a favor, but I feel like we should have a leverage percentage for the North End because we’ ve seen some of these projects where many, many people in the grants, when they’ re writing, they use a lot of our numbers for the North End, especially Niland. And we are a very disadvantaged environmentally and economically disadvantaged community. And it’ s kind of disheartening when big industries like this come. We welcome you. It's a good thing. You know, we’ re starving for economic development. But my concern would be, like if a lot of it stays in the south end, it’ s not really fair. And some people say, well, life is not fair. But at the same time it’ s like we need to some benefits, economic development. We’ re excited about all the industry and all the collaboration that’ s going to happen, that’ s already happening, because I have been participating in some of the workshops with lithium -- the lithium project. I see a lot of good things happening behind the scenes, San Diego State University and Imperial

Valley College, a lot of things going on. So I just want to make sure that the North End gets our fair share. And if you could address the item in regards to the contamination of soil and water? Thank you.

- When you' re talking about bringing jobs into our area, is that STEM education being offered now? Will we be able to catch up to the point when you' re ready to hire that people will be ready to compete for those jobs? What can we do in our area? What can you do to help us to prepare our locals to take those jobs?
- Is there any internship or apprenticeship programs going on now for what' s coming to our valley?
- And I (indiscernible) a question, I think, for all of us. The majority of this meeting should not have been you all talking to us about you listening but, instead, you were listening from (indiscernible). Having a public meeting on a more consistent, on a monthly basis, as you all have had up until now, the Lithium Valley Commission is what I' m talking about, even if it is translated, that is not sufficient to the Public Information Act. This needs to be a public engagement when -- even if they' re held at a monthly meeting, or however the community chooses to have them. They need to be more accessible to community. And when they are provided, like in this space, they should be led primarily by community. I understand that at this point there is a need to answer a lot of questions, like the ones that we, the Leadership Counsel, submitted to the Lithium Valley Commission. But in order to answer those questions and have that conversation with the community, we need to have more community meetings and public meetings like this. And this should not have been done right now. They should have been done eight months ago, nine months ago. This is not acceptable at all. And even in your responses to our questions are these are minimal public health impacts, these are minimal environmental public -- environmental impacts, you haven' t even given us information as to what exactly that means. And that' s why we still have the similar and same questions. Another problem that I have is that all of the conversations that are happening, including comments from community representatives of the Lithium Valley Commission, are suggestive of lithium extraction happening and being, much like the previous commenter said, being such a great thing without, until this point, any sort of communication happening, and that' s really problematic, including things like using the term lithium recovery before even having any conversations until now. And this meeting is the first meeting where I hear that term be used. I don' t know if it was purposefully used in this meeting for the community to give us some sort of positive perspective about. That' s not okay either. So with that and all of this, my question is: How will community be made a central part of the conversation in the decision- making process moving forward? Thank you.
- We' ve been assured that the water within Salton Sea is no way connected to lithium extraction. My question is: Will the Commission oppose privately or publicly the possibility of ocean water import? That is my question.
- Oh, yeah. Hi everyone. So my comment is this, I don' t want to the extraction to happen, period. Say whatever you want, extraction is extraction, especially in a land that has already been severely damaged by state and federal neglect (indiscernible) and pesticides. And you' ve made it very clear that kind of the only, quote unquote, “ benefit” or motivation that' s behind this project is financial gain. So my question is: when we say that we do not want the extraction to occur, is this something that you guys

will actually support when we say this, whether if it' s when you report this to the higher ups to the state or is this just lip service? Because lithium is not a renewable energy source. And I actually want to ask that, if this is like -- if you guys will actually listen to us?

- Thank you for the opportunity. I' d like to direct my question to the industry representatives, Rod Colwell and Jonathan Weisgall. And the question of water supply has been raised and that' s a relevant one. And I think you responded to something tangentially related to that. But I understand from earlier that you' re going to be using the IID interim water supply. And while you have a 90 percent reduction in water use, you still need some. That water supply was set aside to be 25 , 000 acre feet per year. I think about 5 , 000 has already been purchased by Energy Source. Is that going to -- is the remainder of that going to be enough for full lithium development? A related question. We' ve heard from many local residents the concern about dust. And that dust is relevant, both to what' s coming off the desert but, very significantly, fine particles and toxic materials coming off the drying Salton Sea. The geothermal companies are not responsible for that. That' s because we' re selling off water supply to other regions, but it's a legitimate question. And we' re -- and I'm a board member of the Eco Media Compass, a nonprofit located in the West Shores. And we' re hearing from the people we talk to in the community that they' re worried about the thought that because of the plan for developing lithium resources, that officials and industry want to shrink the Salton Sea down even more than it already is. We know that there' s about half of the available Salton Sea KGRA (phonetic) is still underwater. I personally don' t believe it' s necessary to shrink the sea to get at the resource, but could you comment on whether, as industry representatives, you think it' s necessary to shrink the sea in order to drill for the resource? And then a final question related to that is what can industry and development do to help the restoration of the Salton Sea? How can you be part of the solution?
- And my question is the one on the chat, so I' ll just go ahead and elaborate a little bit more. But it' s in regards to the public health and local air and water agencies, more of a question, if the Commission can share any reports or studies or if you' ve seen any reports or studies that look into the public health impacts associated with geothermal, specifically the ones located out here in Imperial County, specifically in the southern end of the Salton Sea? I' m unsure if this information is actually available. I think that without really studying and really understanding the health impacts of what the current geothermals may be adding to the public health conversation, it' s not as easy to say that geothermal or geothermal practices, you know, can be easily dismissed, that they' re not causing any health issues in this area. So as stated before, I think that the California Department of Public Health should be in these conversations, again, to provide input, data, and guidance as this Commission is really looking at providing a report. This component of public health has often been a lens that hasn' t been included, even as we think about Salton Sea and the Salton Sea impacts, but more so in this case. I think we' re trying to jump the line here where, yes, geothermals have been out here for more than 20 years but I' m not sure if it has been studied through a public health lens in regards to what impacts we' ve seen or not. We know that asthma rates are higher, much, much higher in the southern end than in the northern end. We do have the Salton Sea in common but I think there is underlying layers, intersectional layers that may contribute to that. So I think, for me, it' s just a question of really looking into reports or

studies that further look into the public health component as it relates to the current geothermals as, you know, this Commission is looking at the further impacts or added impacts when it comes to lithium. So again, the request is really to bring into the conversations and be a part to bring California Department of Public Health.

- So you know, my name is Mike Dea. I' m with the Laborers' International Union Local 1184 here in Imperial County out of El Centro. And we' ve got probably, approximately, 1 , 000 to 1 , 200 members that live and work in the Imperial County. And we are well behind these projects. I mean, these jobs create -- these jobs that these developers are going to create not only benefit the community but the surrounding communities with longevity jobs. And you know, I' m hearing a lot of comments about the environmental impacts. And as someone who reviews those impacts, the EIRs, and makes sure that developers and contractors build correctly and securely and safely, not only for the workers but for the surrounding communities, these developers that are looking into the lithium industry -- and I' ve been a 26 - year resident of eastern Riverside County and driving down the Highway 6 corridor and heading down, and they' re building solar fields with our members – look out for them and their safety. I think that these community workforce agreements that congressman -- or Assemblymember Eduardo Garcia is looking to do are great for the community and ensures local hire, local apprenticeship progs are contributed to, you know, for our members and their grandchildren and their nephews and aunts and uncles, the people that live in these communities that need these jobs to buy homes and to buy food. And not only those -- for those reasons, the benefits that these jobs provide to the membership. I mean, they get full health and welfare, and dental and vision, prescription. And I can go on and on about how crucially important jobs are. There' s nothing more important to residents in the Imperial Valley than a job and to be able to provide for their families. And these developers come into this area to put all the risk, all the money, all, everything that' s required to build these projects, so we need to support them. I agree, we need to make sure that they' re built safe and sound as possible as far as the environmental impacts. I look at EIRs constantly to make sure that they' re doing these things. So again, I apologize if I' m at the wrong particular moment in time. I' ve been listening to this for, now, two- and- a- half to three, almost three hours, and these are all great questions. And we are stakeholders and we should have these forums. And I appreciate the Committee and what you guys are doing to make sure these things happen. So again, if there' s anything LIONA (phonetic) could do to help or be assistive of anything, we' re here to help and to make sure these things are built correctly.
- Thank you for hosting this and inviting the community, such as myself. I was just wondering if the geothermal people here today could speak on exactly where the brine of the so- called injected, as it' s usually called in the media, back into -- where does that go exactly? Does that eventually end up in the Salton Sea or does that go on – somewhere on their parcel of property? Is there anywhere that we can maybe, as independent researchers, take a look at those impacts ourselves? Because that' s kind of hard to find. The other kind of comment I have is that, with all due respect to the maybe last commenter who made a comment, jobs don' t fix the health issue. And the health issue is the real pressing, immediate priority here. And jobs are great but jobs don' t save lives immediately in the way that they

need to be saved down there at the Salton Sea today. And so that' s what a lot of people are pressing upon, the health issues and the environment, because if we ignore and keep on ignoring this environment, we say, oh, we' ve been down there for 30 years, but you can just say the same that, as the other person said, that the asthma rates are high, you could just as easily say that those extraction processes may have accelerated the issues that we are seeing today. So I' m just mainly wondering, where exactly can we kind of look where the brine is going physically? Thank you very much for your time.

- I just have a real simple question. I' m a pretty simple guy. I' m confused at how you' re extracting the lithium from the Salton Sea but you' re not using water from the Salton Sea. If you can explain to me how -- what this reservoir is and what its relationship is to the Salton Sea, I' d be a little more clear in how you' re using water sources but you' re extracting lithium from the Salton Sea. So if someone could explain that to me, I' d appreciate it.
- I just wanted to echo what community has been asking for, a public health Commissioner or someone to also guide and give that perspective, as well, as that should be a concern for the community and has been mentioned multiple times tonight. So I really wanted to stand in solidarity with that. But I also have a question in regards to what research is being done with like community benefit agreements? And as the recovery process would continue and more developers would want to invest, what would be the maximum; right? Like where does the stop? Like how many acres around the Salton Sea and the Imperial Valley and Coachella Valley will be taken up by this industry in the future? And I think that' s important to know, right, because a lot of the issues that we have now were because things weren' t projected and looked at in a wholistic view. So I think that' s something that' s really important for this Committee, these Commissioners to look at, like what is the maximum? When is enough?
- "Development of lithium brine recovery technology represents competition for existing suppliers of lithium internationally, as mentioned. What is the opportunity for existing suppliers to pivot and undermine the ability of domestic production to become sufficiently competitive to secure long- term investment?
- " There is a lot of mention of job creation. Will the lithium extraction companies actually offer these jobs to community members that don' t have the required training and invest the money in training them, or will the companies import workers from other municipalities that already have the necessary training that' s not benefitting the local community?"
- "I am encouraged by the rationale fact- based discussion I have heard so far in today' s meeting. I especially appreciate the Commissioners support for improving local economy and education. One of the biggest questions from local residents is how do the Commissioners anticipate that the lithium extraction companies will support the restoration of the badly degraded Salton Sea? The biggest concern in this regard is controlling the emissions of toxic dust from the contaminated salt deposits of the playas/ beaches of the Salton Sea. Please provide actual specifics."

Meeting #4: LCJA Junta Comunitaria, 1/18/2022

Questions and comments

- Is there some type of kill switch if there is an immediate or large enough environmental damage that needs to be cleaned up?
- Where will they get water? We are in the desert in peak drought conditions, we can't provide potable water to our residents and farmworkers. Where do we all of a sudden get this magical water supply to operate a facility that consumes 50,000 gallons of water a day?
- Request for reports and research that come from objective organizations, not from reports that the companies involved need to publish
- Request for information about how environmental impacts will affect public health
- Comment that money or employment is not an acceptable trade for public health
- Request for informational materials that use accessible language and minimize technical jargon

Meeting #5: LVC Community Workshop, 10/16/22

Location: Niland, CA
Attendance: ~20-25 participants
Format: In-person, facilitated discussion

Questions and comments

- Have any major automakers expressed interest in supporting the development of the lithium industry given the policy announcements about EV sales targets and banning ICE cars?
- Workforce development
    - Will residents of Riverside be eligible for workforce development programs? Language in recommendation is "local residents" – how will this be defined?
    - Someone else commented "why would they extend it to Coachella? They won't be affected"
    - Workforce development should be accessible to the public, not just limited to the union (re: rec #2 about PLAs)
    - For future generations, teachers could develop curriculum to raise kids' awareness of what's going on in their community so kids have the interest to study engineering
- General back and forth re: "Who/Where is Lithium Valley"
    - "Lithium Valley is a concept" says the CEC, not necessarily a physical space
    - Issue w/ communities trying to become part of the scene when they're not close by. People from Niland and Bombay Beach gave the example of Julian that is far away—"why are they trying to get a piece of the pie"
- Recommendation that Lithium Valley communities/ "local community"/whatever should be defined based on who will experience environmental impacts
- Unincorporated towns need a specific voice and representation because they don't have their own government
    - Niland, Bombay Beach
- What benefits are most important for communities on the frontlines?

  - There is no work here, most young adults want to be able to support their families. She would like to see internships and apprenticeships, for high school grads but also for people who are a bit older and maybe have been working in the fields and want another career. High school and beyond
- How far in advance will they start building infrastructure?
- Need to improve roads before traffic starts coming through
- People need to actually come live in the area to stimulate commerce and revenue
  - G3 à business service center: One may not be enough and if it's in El Centro (which they (the residents) think it will be) people won't be able to access it.
- Similarly—SDSU Center needs satellites in communities closer to the sea, Brawley isn't accessible
- Recommendation on funding research about impacts?
  - Where will funding come from? Will it come from the tax? If it is from the tax there should be a cap on how much is spent on research, otherwise they will just spend money on studying the impacts and not do anything—"environmental studies bleed all the money"
- Econ Rec #1 re: subsidizing electricity rates à add something about water rates, Calipatria and Niland have exorbitantly high water rates because they're on Gold Coast (?) not IID
- Report is missing data from studies on environmental impacts, just say it's minimal but do not point to third-party research
- Recognition of benefits + concern about impacts
- Who will administer programs and provide oversight?
- Benefits should focus on where impacts occur
- Workforce development needs to meet the community where they're at re: existing education levels and when people are available

Meeting #6: LVC workshop 10/17/22

Location: North Shore, CA
Attendance: ~20-25 participants
Format: In-person, facilitated discussion

<u>Questions and comments</u>

- Request to define Lithium Valley
- We know that whatever impact happens—infrastructure, environment, health—whatever is close to the lake will impact everyone. Communities in ECV are being excluded, it's unjust to the communities that will be impacted because we are affected by many illnesses
- What is Lithium Valley?
- What impacts will there be when they take out the water and reinject it? What is the speed?
- Why is the water hot?

- Can reinjecting the water provoke earthquakes?
- We are in a drought, where are they going to get so much freshwater to use? It's important that they explain all of this to us. Where will they get the water from or will they take water from communities around the lake?
- What chemicals will be in the vapor? It's important to explain this because citizens have more illnesses everyday
- Recommend posting information more intentionally on social media; make shorter posts, post on facebook, twitter, Instagram, different modes to reach different age groups and demographics
- Recommendation to do more research. There will be impacts, who will pay for impacts? There are already health impacts and studies but nobody pays
    - They should establish a fund for research and mitigation at the same time
- What is the timeline for studies to analyze the impact? There should be information about before and after and studies that continue to monitor the impact
- Recommend that studies be conducted by an independent party
- ECV won't get benefits but will be put at risk. "Los daños van a ser iguales" à the damages Will be the same
- Community is not respected, they already wrote the draft so the community is a low priority
- Population is undercounted in the area because people aren't registered, aren't counted in the census, people are undocumented
- La salud no se puede solucionar con dinero à health can't be solved with money
- ECV has a lot of illnesses and everyone suffers because of what happens with the Salton Sea
- Request more specificity about what is meant by "CEQA should be the floor and not the ceiling"
- The State doesn't complete what they say they will, they are full of plans without action. They do everything on the short term
- CEC gave packets of information but there is still no information on what the damages will be
- $ shouldn't go to Coachella or Indio
- Request for long-term study and communication to communities
- Everyone who is potentially affected should receive benefits
- Request to bring in a technical expert to answer questions
- Request to include more images in public communication

Meeting #7: LVC workshop 10/18/22

Location: Salton City, CA
Attendance: 5 participants
Format: In-person, facilitated discussion

Questions and comments

- Have they informed the community about the CEQA process? Is that information in the report? A lot of people don't know what CEQA is
- How often will they monitor health impacts? Recommendation that they monitor annually
- Whenever something happens non-profits "drop in like flies and get grants," put monitors in and then never come back to check them
- They should formulate requirements before they give permits, if they already gave permits then ??
  - Under what conditions will companies get permits?
  - If they get permits and then there are damages, who will hold them accountable?
- We are the last ones to know, when did the community approve this happening?
- They try to distract you with $$ when you ask about health impacts
- People talk about benefits, but what good is it going to do if they have health issues?
- Status of development is unclear
  - CEC explained only Energy Source has CEQA approval
- Where will they store lithium?
- Use of analogies is good, use more. Graphics and analogies in report are good
- What types of jobs will be created?
  - Information about # and type of job was not in the report and should be
  - What training is needed for those jobs?
- What divisions and agencies did they consult with?
- Where is the water coming from?
- Who monitors the air quality around geothermal facilities? Monitoring needs to be in place before project starts
- Sentiment that things are already in process by the time these things (i.e. workshops) happen
- There are already health impacts and nothing has been done

A2. Chapter 2

A2.1. Life Cycle Inventories

A2.1.1: LDH sorbent inventory

A2.1.2: NMC811 pCAM Inventory

Inputs			
Flow	Inventory dataset	Units	Quantity per kg NMC 811-OH

Wastewater, unpolluted		m3	
Heat		MJ	40.74414693
Nickel Sulfate (NiSO4)	GLO: market for nickel sulfate	kg	1.34
Cobalt Sulfate (CoSO4)	RoW: market for cobalt sulfate	kg	0.168
Manganese Sulfate (MnSO4)	GLO: market for manganese sulfate	kg	0.163
Sodium Hydroxide (NaOH)	GLO: market for sodium hydroxide, without water, in 50% solution state	kg	0.89
Ammonium Hydroxide (NH4OH)	RNA: market for ammonia, anhydrous, liquid	kg	0.124
Cooling water	Water, cooling, unspecified natural origin [Water]	m3	
Factory	RER: chemical factory construction	Number of pieces	7.11E-10
Outputs			
Name	Flows	Units	Amount
NMC811 Hydroxide	NMC811 hydroxide	kg	1
Ammonia (emissions to air)	Ammonia [Inorganic emissions to air]	kg	0.005809622

A1c: NMC 811 CAM Inventory

Inputs			
Flow	Inventory dataset	Units	Quantity per kg NMC 811-OH
Ni0.8Co0.1Mn0.1(OH)2	{output of pCAM inventory}	kg	0.949
Lithium Hydroxide (LiOH)	DLE LiOH	kg	0.246

Electricity	geothermal/WECC	MJ	26.136
Factory	GLO: chemical factory, organics [allocatable product]	pcs.	7.40E-10
Outputs			
Name	Flows	Units	Amount
NMC811 oxide	NMC811 oxide	Mass	1
Water vapor	Water [non-urban air or from high stacks]	Volume	0.000196

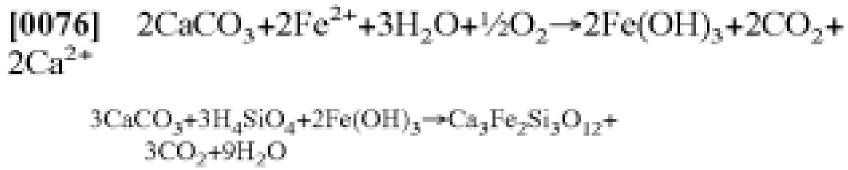
A1d: NMC 811 Cell Inventory

Name	Ecoinvent flows	Amount per kg cell	Units
Anode	RoW: market for anode, silicon coated graphite, for Li-ion battery	0.2181	kg
Cathode	{Output of CAM LCI}	0.3773	kg
Aluminum collector foil	GLO: aluminium collector foil, for Li-ion battery [46430: Parts of primary cells, primary batteries and electric accumulators (including separators)]	0.0284	kg
Wrought alluminum	GLO: aluminium, wrought alloy [allocatable product]	0.0284	kg
Separator	GLO: battery separator [allocatable product]	0.0182	kg
Factory	RER: chemical factory, organics [allocatable product]	4.00E-10	pcs.
Copper collector foil	GLO: copper collector foil, for Li-ion battery [46430: Parts of primary cells, primary batteries and electric accumulators (including separators)]	0.1243	kg
Copper anode	GLO: copper, anode [41412: Unrefined copper; copper anodes for electrolytic refining]	0.033	kg
Electrolyte	GLO: electrolyte, for Li-ion battery [35470: Chemical elements and compounds doped for use in electronics]	0.1683	kg
Plastic film	GLO: extrusion, plastic film [allocatable product]	0.004	kg

Plastic (polyethylene)	GLO: polyethylene terephthalate, granulate, amorphous [allocatable product]	0.0028	kg
Plastic (polypropylene)	GLO: polypropylene, granulate [allocatable product]	0.0012	kg
Sheet rolling, aluminium	GLO: sheet rolling, aluminium [allocatable product]	0.0284	kg
Sheet rolling, copper	GLO: sheet rolling, copper [allocatable product]	0.033	kg
Heat	Scenario-based: geothermal or natural gas	13.291	MJ
Electricity	Scenario-based: geothermal, WECC, or SERC	4.54176	MJ

A2.2. Pretreatment Methods

We model pretreatment based on the process described in Featherstone (2020). There are two impurity removal steps: one that removes iron-rich silica, and a second that separates manganese and zinc. Both use a precipitation and clarification process that produces filter cake, which could either be disposed of as wasted or further treated to recover the minerals in usable form. We assume that the iron silica filter cake is managed as a waste stream, while the zinc and manganese will be a marketable product. This is consistent with the assumptions used in ESM's Draft Environmental Impact Report (DEIR). To precipitate iron and silica, the operators pump air into the brine, which causes dissolved iron to oxidize. Limestone is also added to maintain the pH levels around 5.5. According to the patent, this reaction precipitates iron and silica according to the following stoichiometry:



[0076] $2CaCO_3+2Fe^{2+}+3H_2O+\frac{1}{2}O_2 \rightarrow 2Fe(OH)_3+2CO_2+2Ca^{2+}$

$$3CaCO_3+3H_4SiO_4+2Fe(OH)_3 \rightarrow Ca_3Fe_2Si_3O_{12}+3CO_2+9H_2O$$

The precipitated solids settle in a clarifying tank, and a “relatively clear” brine overflow passes to the zinc and manganese precipitation stage. There, recycled precipitate see and slaked lime are added to precipitate zinc, manganese, and lead (?) oxides and hydroxides. The solids settle in a clarifying tank and the underflow is reused as seed or filtered. The filter cake is then washed and disposed of.

Quantifying inputs and byproducts

The DEIR associated with this process provides some insight as to the quantities of solid waste and byproducts that will be generated during pretreatment. Assuming a processing rate of 7,000 gallons per minute (gpm), they estimate the facility will generate approximately 115,000 metric tons of iron-silica filter cake per year(Draft Environmental Impact Report for.., Section 4.12-20.). However, elsewhere in the DEIR, they report a value of 136,200. According to a representative from the company, this estimate assumed a moisture content of 50-60% (M. Garska, personal correspondence, Feb. 22, 2024). This indicates that the total amount of solid waste compound produced is between 46,000 (assuming the lower output and higher moisture content) and 68,100. We use the mean of these values, which is 57,050.

We assume that $Ca_3Fe_2Si_3O_{12}$ is the solid waste output and, following the equation above, use a molar ratio of 5:1 $CaCO_3$ to $Ca_3Fe_2Si_3O_{12}$ to estimate the amount of CaCO3 required. According to the draft environmental impact report for their demonstration facility, the process is expected to generate 136,200 metric tons of solid waste per year, assuming a processing rate of 7,000 gallons per minute and annual production of 20,000 MT LiOH. We calculate using the following equation, based on the molar masses of $CaCO_3$ and $Ca_3Fe_2Si_3O_{12}$:

$$\frac{\left(5\ mol \times \frac{100.9g}{mol}\right) CaCO_3}{\left(1\ mol \times 508.17\frac{g}{mol}\right) Ca_3Fe_2Si_3O_{12}} = \frac{X\ MT\ CaCO_3}{57{,}050\ MT\ Ca_3Fe_2Si_3O_{12}}$$

This yields an input of approximately 57,000 MT $CaCO_3$. In addition, the process is estimated to emit five moles of carbon dioxide per mole of $Ca_3Fe_2Si_3O_{12}$ output. The equation below is used to calculate the total CO_2 emissions resulting from this reaction:

$$\frac{\left(5\ mol \times \frac{44.01\ g}{mol}\right) CO_2}{\left(1\ mol \times 508.17\frac{g}{mol}\right) Ca_3Fe_2Si_3O_{12}} = \frac{X\ MT\ CO_2}{57{,}050\ MT\ Ca_3Fe_2Si_3O_{12}}$$

This yields approximately 25,000 MT CO_2 per year. The table below calculates the quantities of material required and emitted per-kg of LiOH:

Material	Amount per year (MT)	kg per kgLiOH
Ca3Fe2Si3O12	57,050	2.85
Solid waste (wet, 55% moisture content)	126,778	6.34
Calcium carbonate	56,638	2.83
LiOH	20,000	1.00
CO2	24,704	1.24

The DEIR also estimates that for each truckload of lithium product, the facility will generate three truckloads of zinc product and four truckloads of manganese. However, not enough information is provided about the zinc and manganese precipitation or purification to estimate the impacts of these processes. We therefore exclude these processes from our scope and assign neither a burden nor a displacement credit.

A2.3. LiOH Impact Results

LiOH Production Impact Assessment Results, All Impact Categories

Impact Category	**DLE**	**Brine**	**Spodumene**	**Ecoinvent Market**
Land use	2.47E-01	3.24E-01	4.77E-01	3.99E-01

global warming potential	7.18E+00	6.30E+00	2.05E+01	1.51E+01
Human toxicity potential, cancer	1.06E+00	1.87E+00	2.51E+00	2.29E+00
particulate matter formation potential	1.11E-02	1.15E-02	4.59E-02	3.25E-02
Human toxicity potential, non-cancer	1.27E+01	1.70E+01	7.06E+01	5.39E+01
Freshwater consumption	1.03E-01	7.87E-02	1.54E-01	1.31E-01
Terrestrial ecotoxicity potential	4.34E+01	5.65E+01	2.41E+02	1.84E+02
Metal depletion	3.09E-01	2.23E+00	4.57E+00	3.77E+00
Marine eutrophication potential	9.39E-04	2.76E-03	1.41E-02	1.02E-02
Freshwater eutrophication potential	2.20E-03	4.23E-03	1.08E-02	8.05E-03
Marine ecotoxicity potential	1.09E+00	1.72E+00	9.74E+00	7.26E+00
Ionizing radiation	2.11E-01	3.60E-01	7.33E-01	5.53E-01
Terrestrial acidification	3.05E-02	2.37E-02	1.14E-01	8.37E-02
Climate change inc. biogenic	8.20E+00	7.06E+00	2.15E+01	1.59E+01
Photochemical ozone	1.36E-02	1.66E-02	6.56E-02	4.83E-02
Stratospheric ozone	1.38E-06	1.42E-06	6.21E-06	4.63E-06
Freshwater ecotixicity	1.90E-01	3.25E-02	1.00E-01	7.75E-02
Photochemical ozone ecosystems	1.40E-02	1.72E-02	6.72E-02	4.96E-02
Fossil depletion	1.47E+00	1.75E+00	5.96E+00	4.35E+00

A2.4. Hub Capacity Scenarios

A2.4.1. Maximum production hub

Product	Annual Production	Unit product	Energy Consumption (GWh)	Power required (MW)	Water Consumption (M3)	Process water consumption (AFY)	% of water budget
LiOH	44000	MT LiOH	339	39	12128614	9833	39.33%
pCAM + CAM	178862	MT CAM	3142	359	2929588	2375	9.50%
Cell	128245	MWh Cell	4028	460	2593065	2102	8.41%
Geothermal	7509532	MWh Energy			16918461	13716	54.86%
Total			7510	857	34569728	28026	112.10%

A2.4.2. Sustainable hub

Product	Annual Production	Unit product	Energy Consumption (GWh)	Power required (MW)	Water Consumption (M3)	Water consumption (AFY)	% of water budget
LiOH	44000	MT LiOH	339	39	12128614	9833	39%
pCAM + CAM	147837	MT CAM	2597	296	2421431	1963	8%
Cell	106000	MWh Cell	3329	380	2143281	1738	7%
Geothermal	6,265,764	MWh Energy			14116338	11444	46%
Total			6266	715	30809663	24978	100%

A2.4.3. Hub with double lithium production

Product	Annual Production	Unit product	Energy Consumption (GWh)	Power required (MW)	Water Consumption (M3)	Water consumption (AFY)	% of water budget
LiOH	88000	MT LiOH	678.11	77.41	24,257,228.16	19,665.68	79%
pCAM + CAM	41841	MT CAM	735.09	83.91	685,310.63	555.59	2%
Cell	30000	MWh Cell	942.28	107.57	606,588.87	491.77	2%
Geothermal	2,355,481	MWh Energy			5,306,737.14	4,302.25	17%
Total			2,355.48	268.89	30,855,864.79	25,015.29	100%

A2.5. Waste Streams

Table A2.5.1: Estimated annual waste generated per year under the Sustainable Hub scenario

Product	Annual waste (MT per year)	Hazardous*	Nonhazardous
Geothermal	198,394	91,261	107,133
LiOH	299,200	29,920	269,280
CAM	16,102	12,881	3,220
Cell	110,409	44	110,365

Total	624,105	134,107	489,998

*Does not include spent NMP

Table A2.5.2: Anticipated waste streams from DLE and geothermal energy production under the Sustainable Hub scenario (44 ktons LCE and 6.8 TWh geothermal per year). Source: DOE. 2023a

Product	Description	Reported production rate
Geothermal energy	Iron-silicate filter cake, brine pond solids, solids generated during plant maintenance.	0.03 MT per MWh [18]
Direct lithium extraction	Filter cake	6.8 MT per MT LiOH [42]

Table A2.5.3: Anticipated waste streams from CAM production. Source: [55]

Description	Sample facility estimated annual production (MT per year)	Hub estimated annual production (MT per year)
Recovered electrolyte	659	3,246
Purification sludge (hazardous)	2,584	12,734
Waste oil	4	18
Recovered oil residue	11	54
Onsite laboratory wastewater (hazardous)	109	537
Calcium fluoride- sludges	TBD	TBD

Table A2.5.4: Anticipated waste streams from cell production. Source: (DOE, 2023b)

Description	Sample facility estimated annual production (MT per year)	Hub estimated annual production (MT per year)
NMP scrap	65,317	73,613
Other battery component	17,669	19,913
Electrode scrap	13,225	14,904
Other material	4,000	4,508
Other material (waste)	679	765
Universal + hazardous waste	40	45

A3. Chapter 3

A3.1. Sample interview schedule

“Thank you for agreeing to participate in this study and providing insight about electric vehicle end-of-life logistics. Before we begin, do you have any questions about the study?

To facilitate the interview, I would like to tape our conversation. The recording will be stored confidentially, and I will remove all personal identifiers. Do I have your consent to tape the conversation or would you prefer not to be recorded?”

1. Describe researcher(s) background and purpose of research

2. I’d like to begin by asking you to describe [name of organization] and your role at [name of organization].

3. What are the inputs and outputs of your process?

4. Where do you get vehicles/batteries coming from now and where do you expect them to come from in the future?

5. What information do you need about vehicles/battery shipments when you receive them?

6. Would you say your company has been impacted by vehicle electrification? If so, how?

7. Do you expect your job and industry to change when a higher percentage of cars on the road are electric?
   a. If yes, how so? Do you feel prepared for any upcoming changes?
   b. Ask about cost, logistics, and technical expertise if it does not come up

8. Have you received any formal guidance on how to handle electric vehicles? Safety protocol, etc.?

9. In your understanding, what happens to electric vehicle batteries when the car reaches the end of its usable life?

10. What is your greatest concern regarding EV batteries and what do you see as the greatest opportunity?

11. Is there anything else I should have asked you about electric vehicles or your job?

12. Do you know anyone else I should consider interviewing?
    a. If so, would you be willing to make an introduction or provide me with their contact information?

13. I am planning to produce a report of my observations and findings from these interviews. Would you like a copy? YES____ NO____

A3.2. Stakeholder perceptions of EV transition

Group	Impacts (to date)	Expectations for the future
OEM+ dealerships + parts suppliers	- Fundamental restructuring from gradual improvements in fuel efficiency to full commitment to BEVs (P26) - Changing workforce (P26) - Greater uncertainty due to reliance on charging infrastructure and supply chains (P25) - Company-wide awareness of recycling (P29) - Dealers are just starting to see an influx of more EV models (P22)	- Greater variety of EV options will be available (P25) - More domestic manufacturing and recycling (P25) - Fewer parts mean there will be less maintenance required, which will change dealership service model (P22, P9) - Growth for companies who store EOL batteries (P22) - Changing consumer relationship to cars (P26) - Transportation of EOL batteries will be more efficient (P29) - OEMs will strategize to get batteries back at EOL (P29, P9) - Majority of new demand will be met by recycling (P29) - Workforce will evolve to new skillsets (P29) - More collaboration across value chain (P29) - Will create waves across ecosystems that were constructed to manage ICE cars (P9)
Auto Recyclers*	- More batteries in vehicles (inc. smaller batteries) without awareness, information about them (P21) - Added complexity for dismantling process (P13) - Learning to understand value of battery materials (P24) - Improved safety protocol (P24) - Reduced demand for parts because of lower wear on engines (P7)	- Eventual consolidation of industry; fewer players will be viable (P7) - Changing source of revenue; many parts will be replaced by traction battery (P3, P24) - Market for used batteries will grow - Consistent standards for safe handling → more efficient transportation network (P21) - Greater insight around battery data (P21) - Dismantlers will adapt to handle high voltage batteries with tooling and storage capacity (P2, P17, P21) - More exciting (P24) - Opportunity to leverage network of facilities to aggregate batteries (P24)
Collection & Logistics	- Taking engineering time from other areas (P6)	- Potential for stranded batteries under free market system assuming negative value of recycling (P4)

	- Expanding disassembly area (P6) - Increased volume (P6) - Created more jobs, higher-skilled jobs (P23)	- More damaged batteries early on; increased volumes and greater variety in medium-term; hoping variability decreases over time (P6) - Growth, personal development for employees (P23)
Repurposers	- Created company/ repurposing industry (P15, P18)	- Adapt to batteries with higher voltage and fewer modules (P15) - Develop a universally accessible product (P15) - Percentage of batteries that are repurposed before recycling will increase (P18) - Greater possibility for grid-connected systems (P18)
Battery Recyclers	- Built new facility (P14) - Reason for company; industry growth is driven by EVs (P10)	- More competition, growth in US recycling capacity (P14) - Majority of feedstock will be from EVs (P19, P20, P10) - Automate disassembly process (P20) - Adapt to process structural packs (P20) - Produce different outputs in North America depending on availability of domestic cathode production capacity (P28) - More batteries retiring out-of-warranty → more heterogenous sources, will make things "more fun and interesting" (P28) - Develop capacity to process LFP when market share grows (P28)