Recycling Risk: A Sociotechnical Analysis of the Environmental Injustice in Battery Recycling

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction:

Professor of Chemical Engineering at the University of Virginia, Ron Unnerstall, stated "[In the chemical process industry] what you don't know won't hurt you, it will kill you (R. Unnerstall, personal communication, January 14, 2025)." As the USA pushes itself to electrify its energy economy (Harris & Mose, 2024), it is vital that engineers work to develop better safety practices in processes handling batteries and understand the consequences the industry has on society. The USA is working to electrify its largest energy consumers, such as transportation via electric vehicles. This increasing demand and usage of lithium ion batteries has also increased the amount of spent lithium ion batteries (SLIBs), where studies have shown that 98.3% of these batteries end up being stored in landfills (IER, 2023). These landfills are extremely expensive to operate and deal a significant amount of damage to the local environment as acids, heavy metals, and other hazardous materials can be released and leached into the environment and cause landfills fires that will rage for months at a time (IER, 2023). The remaining batteries are often recycled, most of the time improperly, leading to issues similar to what happened in Northern Georgia in July 2023, when a recycling plant went up in flames due to hazardous scrap batteries being illegally dumped there by a local electric vehicle (EV) manufacturer. In October 2024, the battery manufacturer settled the case by paying the recycling company 31 million dollars (Edwards, 2024).

Currently, the most popular alternative to landfills is battery recycling, where valuable metals from SLIBs are extracted and purified to be reused in battery manufacturing or other industries. Currently the USA can only process about 40,000 tonnes of black mass (Petras, 2024), a fine powder made by shredding SLIBs used as the input to many battery recycling processes, which is about the amount used to power roughly 160,000 Tesla EVs. It is projected that the USA will produce about 650,000 metric tonnes of spent batteries every year by 2044 (D. Scott, 2023). In order to accomplish this, the U.S. Department of Energy (DOE) has pumped $15 million into a ReCell Center to coordinate studies by scientists in academia, industry, and at government laboratories to develop effective methods of recycling spent lithium ion batteries from EVs (Morse, 2021).

One of the most popular methods of recycling SLIBs is hydrometallurgy. Hydrometallurgical technology uses strong acids to leach the metal into the liquid phase for enrichment, and then the liquid phase is further processed to achieve the purpose of recovery (Zhou et al., 2021). This technology is capable of extracting various metals with high specificity and yield, but utilizes hazardous chemicals such as sulfuric acid, hydrogen peroxide, and hydrochloric acid to leach the metals into solution. In Fredericktown, Missouri, a battery recycling plant had released harmful chemicals into the environment, causing hundreds of fish in the local river to spontaneously die (Vasan, 2024). Releases like this have significant effects on the local community and show how the battery recycling industry requires an overhaul in terms of safety.

It is ethically problematic—particularly from a deontological and environmental justice standpoint—to justify compromising the health, safety, and environment of communities hosting battery recycling facilities in the name of advancing renewable energy technologies. These communities are not monolithic; they consist of a diverse array of human and non-human actors embedded in complex relationships with the facility. Actor-Network Theory (ANT) provides an ideal framework for analyzing this situation because it emphasizes the distributed nature of agency and recognizes the interdependence of social, technical, and material elements in shaping outcomes.

ANT allows for a nuanced exploration of how power, risk, and responsibility are negotiated and distributed among various actors—including local residents, plant workers, regulatory agencies, and environmental conditions. By avoiding reductionist categorizations and instead focusing on the dynamic networks through which these actors are connected, ANT facilitates a more holistic understanding of how sociotechnical systems operate and evolve (Warf, 2015). This research will use ANT to identify and map the major actors engaged with battery recycling facilities, examine the positive and negative consequences of their interactions, and propose interventions that enhance safety and ensure just compensation for those disproportionately exposed to risk. Suggestions from professionals in the process safety industry and chemical safety organizations, such as the Chemical Safety Board (CSB), will also be analyzed as to how they can be integrated into current safety practices to further reduce the consequences of battery recycling.

The Major Actors of Battery Recycling:

A battery recycling plant would have many actors that interact with each other and ultimately determine the success of the plant. The plant also directly, and indirectly, affects these actors via monetary value, environmental and health risks, and market goals. The first, and arguably most important social group is the local resident community that exists around the plant. These residents often provide the plant with a workforce to operate the plant, transport necessary parts and ingredients, and other services. What makes local residents so important is that they often determine if a plant has the "mandate to operate." The mandate to operate is the trust that the community puts into the plant that it will provide sufficient economic value, via wages and other means, without putting the public at significant risk (R. Unnerstall, personal communication, January 14, 2025).

The second social group that plays a major role in the success of the plant is the local workforce. The local workforce makes up the managers, engineers, and technicians that design, operate, and oversee the operation of the recycling plant. They receive wages from the company that owns the plant and play a large role in the safety culture of the plant. "Safety culture" refers to the shared attitudes, beliefs, and behaviors within a team or organization that prioritize safety as a core value, where everyone actively participates in identifying and mitigating risks, following safety procedures, and reporting potential hazards, ultimately aiming to prevent accidents and injuries through a collective commitment to safe practices; it is heavily influenced by leadership, communication, and accountability within the workplace (Harbol, 2023).

The third social group is the local government, which includes government provided services such as emergency response and community established groups such as Local Emergency Planning Committees (LEPCs) (Office of Solid Waste and Emergency Response, 1999). They are responsible for enforcing environmental regulations and act as a representative of the local residents. Depending on the political climate and goals of the administration, the government can also enact legislation or fund infrastructure that encourages or restricts the recycling plant.

The final social group is the government. They can control the battery recycling industry via legislation, market controls, subsides, and investment into research. How specific states operate vary widely depending on its current energy market, the goals of its administration, and its land usage. For example, the state of California has a large urbanized population that already uses a significant amount of renewable energy and EVs, meaning it has an established demand for battery recycling, which can be seen in its attempts to pass legislation that will require battery manufacturers to recycle their scrap batteries and spent batteries by 2025 (AB 2440 - Responsible Battery Recycling Act of 2022, 2022).

The other vital actor that needs to be analyzed is the local environment. During chemical releases, the biological environment faces the consequences of exposure to harmful acids and heavy metals, which can drastically affect the local community and thus the reputation of the industry. On the other hand, the physical environment of the region can act as a driving force for the further development of research and development of battery recycling technologies. For example, the US doesn't have any significant domestic lithium or cobalt source that would be able to sustain the exponential growth in demand of lithium ion batteries. On a large scale, recycling could also help relieve the long-term supply insecurity – physically and geopolitically – of critical battery minerals (Machala et al., 2025).

The Relationship between the Actors:

Local Residents:

In general, chemical plants, particularly those located near residential areas, are a significant source of environmental and health risks for surrounding communities. As mentioned by Johnston et al., "Chemical plants release pollutants into the air, water, and soil" (Johnston & Cushing, 2020), which can have detrimental effects on the surrounding population. The paper further emphasizes that "residents in these fenceline communities, who live in close proximity to these industrial sites, are more likely to experience higher rates of respiratory diseases, cancers, birth defects, and other health conditions" (Johnston & Cushing, 2020). This highlights the disproportionate burden that these communities face when living near chemical facilities.

In addition, the environmental impacts of chemical plants, such as "emissions from these plants often contribute to air and water contamination" (Johnston & Cushing, 2020), are not limited to human health but also affect wildlife, ecosystems, and the quality of natural resources. For example, "pollution from chemical plants can lead to soil degradation and loss of access to clean water, which exacerbates inequalities in these communities" (Johnston & Cushing, 2020).

Despite these challenges, communities have a powerful role in influencing the behavior of chemical plants. Johnson et al. notes that "grassroots movements, environmental justice organizations, and local activists play a vital role in holding these companies accountable" (Johnston & Cushing, 2020). These efforts often involve "raising awareness about the dangers of industrial pollution and pushing for stronger regulations" (Johnston & Cushing, 2020). These community-driven campaigns are critical in ensuring that chemical plants are held to environmental standards that protect local residents' health.

"Public policy and regulatory frameworks" are also vital to empowering affected communities, specifically, "policies that require chemical plants to disclose information about emissions and their environmental impact" are highlighted as essential tools for community advocacy (Johnston & Cushing, 2020). By ensuring transparency and pushing for stricter regulations, these communities can demand safer working conditions and more sustainable practices from the chemical plants near them.

Chemical plants have a significant opportunity to improve the lives of those in surrounding communities through proactive engagement and corporate social responsibility (CSR) initiatives. Johnston et al. argues that "corporate social responsibility programs, such as investing in community health, supporting local schools, and contributing to environmental restoration, are ways in which chemical companies can build better relationships with the communities they affect" (Johnston & Cushing, 2020). These initiatives can help rebuild trust and demonstrate that companies are committed to the well-being of local residents, beyond just financial profit. Chemical plants should engage with local communities in meaningful ways, including through community advisory boards, regular public hearings, and transparent reporting on environmental performance (Johnston & Cushing, 2020). These forms of engagement ensure that residents have a direct say in the operations of the plants and can help identify potential hazards before they escalate into major health and safety concerns.

Such initiatives are not without precedent. During Professor R. Unnerstall's tenure at British Petroleum (BP), he facilitated similar community discussions that proved effective in enhancing public understanding of plant operations and the associated risks. These engagements not only reassured local residents about the facility's safety but also fostered mutual accountability and improved the legitimacy of the company's presence within the community. Within the framework of Actor-Network Theory, such forums can be viewed as key nodes of translation—sites where different actors negotiate meanings, align interests, and stabilize shared understandings across socio-technical boundaries.

Local Workforce:

While local residents can play a significant role in regulating chemical plants, chemical plants also hold influence over the local community via its large workforce. For example, in Louisiana, chemical plants can play a pivotal role in the local economy. According to *The Economic Impact of the Chemical Industry on the Louisiana Economy: An Update*, the chemical industry is the leading provider of manufacturing jobs in the state, supporting over $79.7 billion in annual sales (L. Scott, 2018). Chemical manufacturing in Louisiana is renowned for providing competitive wages that contribute substantially to the state's economic engine. The report emphasizes the role of high-paying jobs in driving local prosperity. As the document states, "Chemical manufacturing is not just an industrial activity but a critical engine powering our state's financial vitality, contributing billions to state revenues and generating high-paying jobs (L. Scott, 2018)." This quotation not only underscores the industry's financial impact on the state but also highlights that workers benefit from salaries that are competitive when compared with other sectors. In addition to base pay, workers in the chemical sector often enjoy comprehensive benefits packages—including health insurance, retirement plans, and performance-based bonuses—that help attract and retain a skilled labor force.

These skilled laborers play a vital role in maintaining a plant's safety culture. A robust safety culture is integral to the chemical industry, where even minor oversights can have significant consequences. As emphasized in the *The Economic Impact of the Chemical Industry on the Louisiana Economy: An Update*, there is a strong commitment to continuously developing a skilled workforce that is well-versed in industry safety goals. The update states: "Investment in the development of a skilled workforce is paramount, as it ensures that the talent pool is equipped to meet the rigorous demands of modern chemical processing and production (L. Scott, 2018)." This commitment reflects an understanding that safety is not simply a set of rules but a culture that is nurtured through ongoing training, strict adherence to procedures, and a shared responsibility among all employees. Complementing this view, industry representatives from the American Chemistry Council have noted, "Safety is a shared responsibility that begins with thorough training and continuous engagement with evolving safety practices, ensuring that every employee contributes to a secure working environment (*Responsible Care® Safety and Security By The Numbers*, 2017)." These perspectives highlight that a proactive and educated workforce is essential to reducing workplace hazards and enhancing overall operational safety.

Beyond fostering a strong safety culture, the workforce is the backbone that provides the manpower necessary for the chemical industry's expansive operations. Chemical plants rely on highly skilled workers to manage complex production processes, maintain equipment, and implement safety measures. The document underscores the industry's role as a major employer in the state: “Chemical manufacturing is not just an industrial activity but a critical engine powering our state’s financial vitality, contributing billions to state revenues and generating high-paying jobs (L. Scott, 2018).” This quote reinforces the idea that the availability of a competent and well-trained labor force is vital not only for meeting production targets but also for upholding the stringent safety standards that the industry demands. Experienced personnel are essential for promptly addressing potential safety issues, managing emergencies, and ensuring that safety protocols are consistently followed.

While the economic benefits of chemical plants are undeniable, this very influence can create an uneven power dynamic between industry and local governance. Companies may leverage their role as major employers and economic contributors to dissuade regulatory enforcement or to lobby against the implementation of stricter safety and environmental standards. In some cases, the threat—explicit or implicit—of job losses or reduced investment can pressure local governments into deprioritizing community safety in favor of maintaining economic stability. This kind of economic coercion places surrounding communities in a precarious position, where speaking out against unsafe practices could be perceived as threatening their own livelihoods.

To challenge this imbalance, local labor unions and community-based coalitions can act as critical counterweights to corporate power. By uniting the interests of workers and residents, these groups can advocate for safe, equitable, and transparent industrial practices without undermining the economic value of the facility. When organized effectively, they can push for regulations that prevent companies from monopolizing the local economy, eliminate barriers for competition, and enforce operational standards that prioritize long-term sustainability over short-term profit.

The most effective way for both industry and government to pursue truly sustainable operations—while maintaining public trust and economic viability—is through the establishment and continuous reinforcement of a strong safety culture. A well-developed safety culture not only reduces the risk of industrial accidents but also signals a company's commitment to the well-being of its workers and the broader community.

Government Regulation:

The relationship between governments and the chemical industry is defined largely by the regulatory frameworks that balance public health and environmental protection with industrial competitiveness. Both the European Union and the United States work closely with their chemical industries, but their methods differ significantly. In the EU, REACH represents a proactive model where the government places a substantial burden on industry to demonstrate the safety of their chemicals. This approach is built on the principle that the responsibility for providing safety lies with manufacturers and importers. A quote from a technical comparison of the two regulatory frameworks states: "Under REACH, industry is required to provide comprehensive safety data for each chemical, effectively shifting the burden of proof from regulators to companies (Botos et al., 2019)." This arrangement fosters a more transparent relationship where industry accountability is paramount. In contrast, the U.S. system under the amended TSCA, while making strides in updating chemical oversight, still tends to offer more leeway to industry, with regulatory actions often coming after risks have been identified rather than proactively prevented.

One of the key differences noted in the document is the proactive nature of REACH compared to the more reactive approach of TSCA. In the U.S., the revised TSCA has improved the situation by increasing the EPA's authority, but critics argue that it still does not impose as rigorous a requirement on industry as REACH does. The document states: "While the amended TSCA has expanded the EPA's ability to require safety data, it stops short of fully transferring the burden of proof to the industry, a mechanism that is central to the effectiveness of REACH (Botos et al., 2019)." This means that U.S. regulators often need to initiate testing and risk evaluations themselves rather than receiving robust safety data from the industry.

Another area where the U.S. system appears to lag is in transparency. The REACH regulation is designed to make a wide array of chemical data publicly accessible, thereby enhancing accountability both for companies and regulators. The TSCA, although amended, does not yet achieve the same level of openness. As noted in the analysis, "The limited transparency in the TSCA framework can hinder public scrutiny and delay corrective actions, as critical chemical safety information is not as readily available as it is under REACH (Botos et al., 2019)." This lack of publicly accessible data can reduce stakeholder trust and make it more challenging for communities and advocacy groups to monitor chemical risks.

These comparisons underscore the need for further reforms in the U.S. system to adopt elements of the proactive and transparent approach exemplified by REACH, potentially leading to improved chemical safety and greater public trust. This can be achieved via implementing recommendations from organizations such as the CSB and professionals such as Prof. R. Unnerstall. The US should restructure its regulatory framework to be more transparent, interactive, and proactive, in order to make sure that new battery recycling plants meet all necessary safety standards and are properly designed to prevent and mitigate all major emergencies. This would greatly improve the implementation of the intent of the safety regulations, rather than just solely meeting the physical requirements, leading to major reduction in the number of safety incidents and establishment of an effective safety culture. Paired with increased transparency, these changes will reduce the health and safety risks that the local residents and local workforce are exposed to and increase trust between them and the plant management, cementing the company's mandate to operate. This can be seen in the vast difference in chemical safety incidents recorded in the EU versus the US. According to the EU's eMARS database, the EU has, on average, had 30 accidents per year, since 1994 (Katarina & Samuel, 2024). In the U.S., according to the Coalition to Prevent Chemical Disasters, "On average, there is a chemical fire, explosion or toxic release every two days in the U.S (*Coalition to Prevent Chemical Disasters*, 2021)."

Environmental Conditions:

Environmental justice addresses the fair treatment and meaningful involvement of all people with respect to environmental laws, regulations, and policies. In many regions, communities near chemical production facilities often bear disproportionate environmental burdens. For example, Scott et al. points out that: "While chemical plants provide substantial economic benefits, there must be a balanced approach to mitigate environmental risks and foster positive community relations, ensuring that local populations share in the prosperity generated (L. Scott, 2018)." This acknowledgment underscores that the benefits of chemical production are frequently accompanied by adverse environmental and health effects in nearby communities—effects that are central to environmental justice debates. In areas like Louisiana's

“Cancer Alley,” residents have voiced concerns over disproportionate exposure to pollutants. As reported in an AP News article, one community leader stated, “We are on the frontlines of pollution, and our health and environment are being sacrificed for profit (Brook, 2024).” Such quotations illustrate that while the chemical industry can drive significant economic activity, it also poses risks that fall unevenly across society, intensifying calls for stronger regulatory oversight and remediation efforts to protect vulnerable populations.

The chemical industry is inherently resource-intensive. Its operations depend on a steady supply of raw materials—such as crude oil, natural gas, and various minerals—as well as energy and water. Fluctuations in the availability and cost of these resources can directly affect production costs, market prices, and ultimately product demand. According to Industrial chemical regulation in the European Union and the United States: a comparison of REACH and the amended TSCA, “Resource constraints, such as fluctuations in the availability of raw materials, have a direct impact on chemical production costs and market demand (Botos et al., 2019).” This interplay means that when resources become scarce or prices rise, chemical companies may face increased production costs, forcing them to innovate—either by seeking alternative inputs or by improving process efficiency—to maintain competitive pricing. These market adjustments can shift product demand as industries downstream adjust their purchasing and product formulation strategies in response to price signals and supply limitations. Moreover, sustainability concerns are increasingly driving both consumer and regulatory expectations, encouraging companies to invest in greener technologies and more sustainable sourcing practices.

Conclusion:

This thesis has explored the social, environmental, and political dynamics surrounding battery recycling plants in the United States, particularly focusing on the disproportionate risks borne by the surrounding communities. Through the case of the Exide Technologies plant in Vernon, California, it has become evident that while battery recycling is vital to achieving a circular economy and meeting climate goals, it often comes at a significant human and environmental cost—especially for marginalized populations.

A central finding of this research is that the unequal burden of risk arises from a confluence of factors: regulatory failures, lack of meaningful community engagement, the overpowering influence of industrial actors, and a persistent disregard for the voices and health of affected residents. These dynamics have created a landscape in which the very communities that stand to gain the least from battery recycling bear the greatest cost in terms of pollution, health hazards, and socio-political exclusion.

To move toward a more just and sustainable battery recycling system, several critical interventions are necessary. First, collaborative outreach programs must be established to empower communities with knowledge and voice. These programs can foster transparency, facilitate community input in decision-making, and rebuild trust between residents and industry stakeholders. Second, the dominant influence of recycling plant operators must be checked by robust regulatory oversight and greater accountability to local governance structures. This shift in power dynamics is essential for ensuring that industrial growth does not eclipse public health and environmental justice. Finally, embedding a strong safety culture within recycling facilities—one that goes beyond compliance to proactively identify and mitigate risks—can significantly reduce harm and signal a genuine commitment to ethical industrial practice.

By implementing these strategies, the battery recycling sector can not only reduce the disproportionate risks experienced by frontline communities but also position itself as a cornerstone of a circular economy. Such a transformation is vital for scaling up battery recycling operations across the U.S. in a manner that aligns with national climate ambitions. In doing so, we can reimagine battery recycling not as a trade-off between industrial progress and community well-being, but as a model for sustainable development where environmental responsibility and social justice go hand in hand.

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