

Charging Toward Disaster: The Regulatory Failures of Lithium-Ion Batteries and the Need for Safer and More Sustainable Energy Storage

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I. INTRODUCTION

As the world moves away from burning fossil fuels and toward more electric-powered technology, electricity is widely believed to be a safe, clean alternative energy source. The progress of society is often measured by the development of new tools, devices, and technologies. One such innovation is the progression toward electric-powered devices, which are portable, easy to use, innovative, and make parts of life seemingly effortless. All of these electric-powered devices depend on batteries to store and deliver electricity; without them, most would be little more than useless pieces of junk. Hence, the battery is a pivotal part of these innovative devices. There is a trend toward the use and development of electric cars, consumer electronics, energy storage systems, robotics, and

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medical devices. However, where there is the development and invention of new devices with exciting features, there has been little innovation in the component that powers these devices, the batteries themselves. The widespread use and development of batteries has not changed much since the introduction of the lithium-ion battery, which was introduced to the general population in 1991.¹

While there was a major development behind the use of technology that utilizes electricity as its power source, many people do not consider the harsh environmental impacts of this development and the subsequent use of lithium-ion batteries as the main power source for this technology. The movement away from burning fossil fuels is thought of solely as a positive trend, but many other considerations must be further analyzed.

II. LITHIUM-ION BATTERY

The principal type of battery used in most contexts is the lithium-ion battery. Most consumer electronics such as cell phones, digital cameras, laptops, tablets, power tools, e-cigarettes, headphones, Bluetooth speakers, and many other devices use lithium-ion batteries.² Additionally, power plants and alternative electricity storage sites use larger lithium batteries to store their excess electricity.³ It is one of the most popular types of batteries because it has the best conductivity, and at the moment, it is the most efficient form of battery. A lithium-ion battery is composed of cells containing the active materials, a management system, and a structure to house it.⁴

A. *Advantages of the Lithium-Ion Battery*

To consider why lithium-ion batteries are so widely used it is necessary to first consider the positive aspects that draw companies and developers to use lithium-ion cells to power many devices. First, batteries using Lithium-ion have some of the highest power output on the market

1. See Lithium-Ion Battery, CLEAN ENERGY INST.: U. OF WASH., <https://www.cei.washington.edu/research/energy-storage/lithium-ion-battery/> (last visited Apr. 7, 2025).

2. See Dan Richards, Where Are Lithium-ion Batteries Used?, KADANT, <https://dcf.kadant.com/en/blog/where-are-lithium-ion-batteries-used#:~:text=Lithium%2Dion%20batteries%20are%20versatile,and%20robotics%2C%20and%20wearable%20technology> (last visited Apr. 7, 2025).

3. See MIT Climate Portal Writing Team, *How is Lithium Mined?*, MIT CLIMATE PORTAL (Feb. 12, 2024), <https://climate.mit.edu/ask-mit/how-lithium-mined>.

4. Environmental Impacts of Lithium-Ion Batteries, INST. FOR ENERGY RSCH. (May 11, 2023), <https://www.instituteforenergyresearch.org/renewable/environmental-impacts-of-lithium-ion-batteries/>.

as lithium-ion batteries offer energy density as high as 330 watts per kilogram.⁵ Further, lithium-ion cells in batteries can offer around 3.6 volts, which is much more than other elements can offer in a cell, making it a desirable choice for devices that require a higher energy input to function.⁶ While lithium-ion batteries can deliver up to 4.2 volts per cell, a reduction in the voltage allows the cell to last longer and be recharged more.⁷ Specifically, a battery charged with 4.2-volt cells could recharge about 300-500 times while using 3.9-volt cells could recharge 2,400-4,000 times.⁸ Either way, looking at those numbers, a battery that uses Lithium-ion cells has a long lifespan, and as such, is very popular. These lithium-ion cells also do not contain inherently toxic elements such as lead or cadmium.⁹ Since lithium-ion cells in batteries do not contain these known harmful elements, it is thought of as a safer alternative. However, there are many negatives to combat the positive aspect of all this power produced.

B. *Consequences of the Lithium-Ion Battery*

As useful as lithium-ion batteries are, they also come with harsh impacts that negatively affect the world and the general population in various ways. Specifically, the lithium-ion battery creates negative impacts by the way the lithium is produced and its effect on the environment after its disposal.¹⁰ While there are ways to mitigate the environmental impacts of disposal by recycling the battery, this is sparingly used on a global scale.

III. EXTRACTION

Global production of lithium has skyrocketed as electric devices have developed and become more popular, increasing the need for more lithium.¹¹ Specifically, production has gone from 37,000 tons in 2012 to 130,000 tons in 2022.¹² However, as the battery industry has boomed

5. See CLEAN ENERGY INST.: U.. OF WASH., *supra* note 1.

6. See *id.*

7. See BU-808: *How to Prolong Lithium-based Batteries*, BATTERY UNIV., https://batteryuniversity.com/article/bu-808-how-to-prolong-lithium-based-batteries#google_vignette (Oct. 11, 2023).

8. See *id.*

9. See *id.*

10. See INST. FOR ENERGY RSCH., *supra* note 4.

11. See MIT Climate Portal Writing Team, *supra* note 3.

12. See Brian Jaskula, *Mineral Commodity Summaries: Lithium*, U.S. GEOLOGICAL SURV. (Jan. 2012), <https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/mineral->

more recently, the need for lithium to create those batteries intensified as well. Namely, in 2024, the extraction of lithium for the world totaled 240,000 tons.¹³ The amount extracted nearly doubled from 2022 to 2024. This massive increase signals the change toward increased battery production as 87% of global lithium was used to create batteries in 2024.¹⁴ In contrast, in 2012, only 30% of global lithium production was used to create batteries.¹⁵

Lithium is a rare element and requires intensive extraction from the earth, as it cannot be found by stumbling upon it. There are two main ways that lithium is procured to create the cells for batteries, traditional open-pit mining and brine extraction.¹⁶ The majority of global lithium reserves exist in Chile and Australia.¹⁷

One main option for obtaining lithium, brine water extraction, is disruptive and has various impacts on the environment. However, to obtain lithium, brine extraction is very important as nearly 60% of the world's lithium is found in an area called the Lithium Triangle in Chile, Bolivia, and Argentina.¹⁸ In the Lithium Triangle, the resource is mainly found in the salt flats, an area that is already sensitive and vulnerable to ecological pressures.¹⁹ The process of brine extraction involves pumping water into the salt flats to make salt water containing lithium to rise to the surface.²⁰ Then, once the salt water evaporates, lithium can be filtered out from what remains.²¹ This part of the process does not create much pollution since it vastly relies on the energy from the sun to evaporate the water.²² However, this process has negative impacts on the salt flats. Mainly, the issue is that the process can contaminate the water supply.

pubs/lithium/mcs-2013-lithi.pdf; Brian Jaskula, Mineral Commodity Summaries: Lithium, U.S. GEOLOGICAL SURV. (Jan. 2023), <https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-lithium.pdf>.

13. Brian Jaskula, *Mineral Commodity Summaries: Lithium*, U.S. GEOLOGICAL SURV. (Jan. 2025), <https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-lithium.pdf>.

14. *Id.*

15. Brian Jaskula, *Mineral Commodity Summaries: Lithium*, U.S. GEOLOGICAL SURV. (Jan. 2013), <https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/mineral-pubs/lithium/mcs-2013-lithi.pdf>.

16. INST. FOR ENERGY RSCH., *supra* note 4.

17. MIT Climate Portal Writing Team, *supra* note 3.

18. Lucia Neme & Connor Pound, *Understanding the Social Complexities of Mining in the Lithium Triangle*, THE UNIVERSITY OF QUEENSLAND: AUSTRALIA (May 7, 2023), <https://smi.uq.edu.au/article/2023/05/understanding-social-complexities-mining-lithium-triangle>.

19. *Id.*

20. INST. FOR ENERGY RSCH., *supra* note 4.

21. *Id.*

22. MIT Climate Portal Writing Team, *supra* note 3.

Additionally, this area is one of the driest places on Earth and the process uses about 65% of the region's water supply.²³

The other way to extract lithium from the ground is as ore from open-pit mining.²⁴ This process is also intrusive as it requires using heavy machinery to dig up and crush rocks to find the lithium ore.²⁵ Open-pit mining has a major impact on the environment as it pollutes large amounts of carbon dioxide (CO₂).²⁶ Specifically, projections estimate that the entire process releases about thirty-seven tons of CO₂ for every ton of lithium ore produced, which is more than triple the amount released from brine extraction.²⁷

Both processes used to extract lithium consume a large amount of energy, affect the environment directly in many ways through their intrusive nature, and produce large amounts of pollutants.²⁸ While there are laws in some countries that try to help these regions, the policies tend to fall short of the intended impact and do not safeguard the communities or the environment adequately.²⁹

A. Regulations on Extraction

Although the extraction process poses an intrusion on surrounding communities and the environment, the regulations that are currently in place do not deter undesired outcomes or incentivize good behavior nearly enough. For instance, in California, there is a tax based on the amount of lithium extracted inside the state. There, the state government taxes the extraction operations between \$400 to \$800 per ton of lithium, and the proceeds go toward restoring the environment and the overall benefit of the affected community.³⁰ That number pales in comparison to the market value of unrefined lithium, which fluctuates sporadically, and in 2024 was worth about \$14,000 per ton.³¹

While lithium deposits remain spread out across the world, a growing concern in the United States is the relevance of and dependence on China in the lithium-ion battery market. Presently, China is one of the

23. Andrew Sheldon, *Are Electric Car Batteries Bad for the Environment?*, AAA NETWORK (Apr. 20, 2022), <https://magazine.northeast.aaa.com/daily/life/cars-trucks/electric-vehicles/are-electric-car-batteries-bad-for-the-environment/>.

24. MIT Climate Portal Writing Team, *supra* note 3.

25. *Id.*

26. *Id.*

27. *Id.*

28. *Id.*

29. *Id.*

30. *Id.*

31. Jaskula, *supra* note 13.

world's leaders in refining extracted lithium for batteries, as in 2023 the Chinese markets accounted for 80% of the world's battery cell production.³² In order to reduce these concerns and rising tensions, President Donald Trump passed an executive order in March 2025 to increase the domestic production of many minerals, with lithium among them.³³ The mandate utilizes the Defense Production Act of 1950, which is used to “ensure the adequacy and production of supply” of domestic industries in the interest of national defense.³⁴ Effectively, allowing the president and the executive branch to incentivize domestic production of precious minerals when the foreign supply could be at risk.³⁵ This executive order, as a precautionary measure, was the American response to increasing insecurity of resource imports due to China's recent ban of the exportation of a few precious materials used in technology development, and the increasing tension with Canada over trade.³⁶

As important as domestic mineral security is, it is also necessary to consider the impact that the increased extraction of lithium would have in America, since in many cases, the domestic extraction of lithium would affect Indigenous and low-income communities disproportionately.³⁷ The land that contains lithium stores often houses Indigenous and other rural communities.³⁸ One example of the impact that lithium mining has on Indigenous communities in the U.S. is at the Thacker Pass in Nevada, where a lithium mining operation is potentially violating the community's rights.³⁹ That mining operation raises concerns of impacting the environment through invasive methods to extract lithium and is preventing the local community from accessing sacred land. This effect increases the relevance of a United Nations panel that stated, “urgency of the energy transition cannot justify irresponsible practices in mining” and

32. Phoebe Sedgman, Jinshan Hong & Linda Lew, *China's Stranglehold on EV Supply Chain Will Be Tough to Break*, BLOOMBERG (Sep. 27, 2023, 5:00 AM), <https://www.bloomberg.com/graphics/2023-breaking-china-ev-supply-chain-dominance/?embedded-checkout=true>.

33. Jarrett Renshaw & Ernest Scheyder, *Trump Invokes Emergency Powers to Boost US Critical Minerals Production*, REUTERS, <https://www.reuters.com/world/trump-says-us-sign-minerals-deal-with-ukraine-shortly-2025-03-20/> (Mar. 20, 2025).

34. 50 U.S.C. § 4502(b).

35. Renshaw, *supra* note 34.

36. *Id.*

37. MIT CLIMATE PORTAL WRITING TEAM, *supra* note 3.

38. *Id.*

39. *New Report Finds Nevada's Lithium Mine Permit Violates Indigenous Peoples' Rights*, AM. CIV. LIBERTIES UNION (Feb. 6, 2025, 11:00 AM), <https://www.aclu.org/press-releases/new-report-finds-nevadas-lithium-mine-permit-violates-indigenous-peoples-rights>.

further emphasized that governments need to guarantee the rights of the Indigenous people.⁴⁰

IV. WASTE

The disposal of lithium-ion batteries is the other end of the life cycle necessary to consider for its harsh environmental effects. While there are regulations in place to limit the environmental impacts and incentivize good behavior, these regulations inadequately perform that function. Specifically, to reduce the impact of lithium-ion battery waste, efforts exist to recycle the materials to create new batteries and reduce the need for further extraction. When a lithium-ion battery is not recycled and is disposed of incorrectly, it has harsh impacts that could affect the environment and the surrounding population.⁴¹

Lithium-ion batteries are disposed of incorrectly when they are thrown away in a landfill as ordinary trash, creating a variety of problems.⁴² A recent study estimated that a staggering 98.3% of lithium-ion batteries end up in landfills, which is a serious issue.⁴³ When lithium-ion batteries are disposed of improperly into landfills, the battery cells containing the active materials can release harsh toxins with heavy metals that then contaminate the soil and groundwater.⁴⁴

Additionally, having lithium-ion batteries in landfills increases the likelihood of landfill fires caused by the batteries.⁴⁵ These fires are becoming increasingly common as the concentration of batteries present increases.⁴⁶ For example, one landfill recorded 124 fires over a three-year span that were caused by lithium-ion batteries.⁴⁷ Lithium-ion batteries are prone to combustion or explosion when they are damaged because of the high energy density and the other materials present.⁴⁸ Additionally, a

40. Juliane Kippenberg & Jim Wormington, *UN Panel Affirms Human Rights in Mining for Renewables: Implement Guiding Principles to Bring Just Transition from Fossil Fuels*, HUMAN RIGHTS WATCH (Sep. 11, 2024, 1:44 PM), <https://www.hrw.org/news/2024/09/11/un-panel-affirms-human-rights-mining-renewables>.

41. INST. FOR ENERGY RSCH., *supra* note 4.

42. *Id.*

43. *Id.*

44. *Id.*

45. *Id.*

46. *Id.*

47. *Id.*

48. Phoebe O'Connor and Patrick Wise, *An Analysis of Lithium-ion Battery Fires in Waste Management and Recycling*, U.S. ENV'T PROT. AGENCY OFF. OF RES. CONSERVATION AND RECOVERY 5 (July 2021), https://www.epa.gov/system/files/documents/2021-08/lithium-ion-battery-report-update-7.01_508.pdf.

damaged battery could experience a process called thermal runaway, which is the rapid self-heating of a battery, without combustion.⁴⁹ While the battery does not combust, it heats up so rapidly when experiencing thermal runaway, the increase in heat could ignite nearby materials. As the number of lithium-ion batteries in landfills increases, the danger of more reactions increases, since if not handled promptly, the reaction could spread to other nearby batteries and all other combustible trash.⁵⁰ The danger for this reaction is high when there is any damage to the mechanism, so when the battery is crushed in a landfill, this becomes a likely result.⁵¹ The Environmental Protection Agency (EPA) considers lithium-ion batteries as hazardous waste due to their capacity to ignite or explode if not disposed of properly.⁵²

A. Waste Regulations and Legal Impact

A variety of laws in the U.S. govern policies for the waste of lithium-ion batteries both at the federal and state levels, with the majority occurring federally to ensure uniformity around the country. Yet there is the need for more clarification on the regulatory status of the material.⁵³ One such piece of federal legislation is the Resource Conservation and Recovery Act (RCRA), giving the EPA the authority to “control hazardous waste from cradle to grave.”⁵⁴

The RCRA defines hazardous waste as solid waste that poses a major current or speculative “hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.”⁵⁵ While the RCRA outlines what could constitute hazardous waste, the generic definition is relatively ambiguous as it can be interpreted differently. However, further pieces of legislation go into more detail about hazardous waste and name more specific qualities. One such detail included in the federal code is that if the solid waste has the characteristic of being ignitable when under normal temperature and

49. *Id.*

50. *Id.*

51. *Id.*

52. *Lithium-Ion Battery Recycling*, U.S. ENV'T PROT. AGENCY, <https://www.epa.gov/hw/lithium-ion-battery-recycling> (last updated Sep. 24, 2025).

53. Aaron Goldberg, *New EPA Guidance on Lithium-Ion Batteries Leaves Critical Questions Unanswered*, BEVERIDGE AND DIAMOND (June 7, 2023), <https://www.bdlaw.com/publications/new-epa-guidance-on-lithium-ion-batteries-leaves-critical-questions-unanswered/>.

54. *Summary of the Resource Conservation Act*, U.S. ENV'T PROT. AGENCY, <https://www.epa.gov/laws-regulations/summary-resource-conservation-and-recovery-act> (last updated July 25, 2025).

55. 42 U.S.C. § 6903(5)(B).

capable of burning vigorously to the point it is a hazard, it shall be deemed hazardous waste by the EPA.⁵⁶ Another quality pertinent to the lithium-ion battery is reactivity. Solid waste that can be capable of spontaneous explosion under normal temperature and pressure, subjected to another force, or heated in confinement would be deemed hazardous waste due to the characteristic of reactivity.⁵⁷ While the regulation provides explicit exclusions, lithium-ion batteries are not included on that list, and it even includes that items can only meet the exclusion from the hazardous waste classification if the item does not have lithium-ion batteries present.⁵⁸

With most lawsuits settling before trial for monetary punishment and not imprisonment, the punishment for the companies is relatively minor, especially when considering how much money these companies make annually on their products. Further, the lack of cases that go to trial demonstrates how inadequate the regulations surrounding lithium-ion battery waste are and the need to continue to develop the regulations as the field of batteries continues to progress. For example, one recent lawsuit was settled for \$31 million, including \$20 million in punitive damages and \$11 million in compensatory damages, because a battery manufacturer did not disclose to a waste company that the waste contained lithium-ion batteries, leading to their improper disposal.⁵⁹ While that large settlement may dissuade some battery companies from intentionally or negligently disposing of lithium-ion batteries improperly when dealing with larger companies, the best form of deterrent is criminal punishment.

While there are criminal penalties under the RCRA, these penalties can be manifested as either fines or incarceration.⁶⁰ The harshest of the criminal penalties under the RCRA carries a \$250,000 fine and/or 15-year imprisonment, which requires a knowing endangerment standard.⁶¹ When carried out by an organization and not just by an individual, the fine can reach “not more than \$1 million.”⁶²

56. 40 C.F.R. § 261.21.

57. 40 C.F.R. § 261.23.

58. 40 C.F.R. § 261.4.

59. Shelley Mann, *Metro Site Wins \$31M Settlement After Lithium-Ion Battery Fire*, WASTE TODAY, <https://www.wastetodaymagazine.com/news/metro-site-wins-31m-settlement-after-lithium-ion-battery-fire/> (Nov. 19, 2024).

60. Criminal Provisions of the Resource Conservation and Recovery Act (RCRA), U.S. ENV'T PROT. AGENCY, <https://www.epa.gov/enforcement/criminal-provisions-resource-conservation-and-recovery-act-rcra> (Mar. 3, 2025).

61. 42 U.S.C. § 6928(e).

62. *Id.*

Further, the criminal penalties for improper disposal of hazardous waste under the RCRA have a requirement of “knowingly” performing the violating act.⁶³ This requirement creates a higher standard for the alleged offender to be convicted, making enforceability more difficult. The standard was further discussed in *United States v. Baytank, Inc.*, to create a clearer definition of the “knowingly” requirement in the RCRA.⁶⁴ There, the court determined that “knowingly” means that a person or organization knows that they are storing/disposing of something, what they are storing, that the material can potentially cause harm to people or the environment.⁶⁵ By clarifying the definition there, the Fifth Circuit actively removed the defense that someone did not know that the material was defined as a hazardous waste under the RCRA.⁶⁶ Thus, it remains easier to hold bad actors accountable for their actions that can adversely affect the environment, even if the penalties do not serve as an adequate deterrent.

V. RECYCLING

One way to drastically reduce the impact of lithium-ion batteries is through the recycling of discarded batteries. The practice of recycling batteries keeps them from ending up in landfills and reduces the need to extract additional materials from the earth as the metals can be repurposed for future use.⁶⁷ However, the process of recycling batteries is difficult since damaging the battery or disassembling it incorrectly could lead to the release of toxic fumes or fires.⁶⁸ Further, even though prices for lithium extraction and producing batteries continue to increase, it remains cheaper and easier for businesses to continue extracting rather than use recycled battery materials.⁶⁹ On top of the price difference, presently, to produce a new battery, the associated material and energy requirements are less than what is necessary to recycle a lithium-ion battery for future use.⁷⁰

Since batteries are all different, it is difficult to create uniform, efficient recycling centers that can correctly handle all types of batteries.⁷¹

63. 42 U.S.C. §§ 6928(d)(1)-(7).

64. 934 F.2d 599, 612 (5th Cir. 1991).

65. *Id.* at 613.

66. *Id.*

67. INST. FOR ENERGY RSCH., *supra* note 4.

68. *Id.*

69. *Id.*

70. *Id.*

71. *Id.*

After all, batteries were not produced with the thought of how to make the recycling process as easy as possible. The process of recycling lithium-ion batteries carries a high cost because it cannot be easily accomplished through automation, requiring more human attention.⁷² On top of the need for human assistance, the process of gathering the recycled material from the battery requires large amounts of work, which is labor-intensive.⁷³ First, the battery must be taken apart and there are two main ways to disassemble a battery: manually or by shredding.⁷⁴ Manually disassembling a battery allows more components to be salvaged but requires a lot of labor and potentially exposes workers to the harsh nature of the batteries.⁷⁵ Shredding the battery, by contrast, protects the workers and is the simplest method, but does not allow the battery casing or other components to remain undamaged.⁷⁶ Both of these strategies remain imperfect, but a necessary step in the process of breaking down a battery for the materials to be recycled and reused.

Next, the three main techniques used to recycle the lithium metals, or the active materials, from the disassembled battery are hydrometallurgy, pyrometallurgy, and direct recycling.⁷⁷ While direct recycling is the simplest method to recycle the materials, the battery must be in good condition as it is not being treated by an outside factor like the other methods.⁷⁸ Direct recycling thus has a smaller number of batteries that are acceptable for the process and a higher overall amount of labor required causing higher recycling costs, but it allows for the highest level of recovery of materials.⁷⁹ Meanwhile, hydrometallurgy uses liquid solution to extract the metals and materials from a battery.⁸⁰ As a result, this process has lower energy costs but utilizes a substantial amount of wastewater requiring further treatment.⁸¹ Lastly, pyrometallurgy, melts

72. CAS SCIENCE TEAM, *Lithium Ion Battery Recycling: A Review Of The Current Methods And Global Developments*, AM. CHEMICAL SOC'Y 2 (Sep. 2, 2022), https://cdn.prod.website-files.com/650861f00f97fe8153979335/6580b2234c38e5126356f4ec_CASGENENGWHP100560220101-LIB_Recycling-White-Paper.pdf.

73. INST. FOR ENERGY RSCH., *supra* note 4.

74. CAS SCIENCE TEAM, *supra* note 72, at 4.

75. *Id.* at 6.

76. *Id.*

77. *Id.* at 3.

78. *Id.* at 6.

79. CAS SCIENCE TEAM, *Lithium Ion Battery Recycling: A Review Of The Current Methods And Global Developments*, AM. CHEMICAL SOC'Y 6 (Sep. 2, 2022), https://cdn.prod.website-files.com/650861f00f97fe8153979335/6580b2234c38e5126356f4ec_CASGENENGWHP100560220101-LIB_Recycling-White-Paper.pdf.

80. *Id.* at 5.

81. *Id.* at 6.

the battery, usually in a furnace to melt down the materials into metal compounds.⁸² Each method has its advantages and drawbacks, but they remain the main methods of recycling the precious materials found inside batteries. Battery recycling is an important approach for gathering the necessary materials for future batteries that does not require intensive extraction from the ground. However, while this process is not perfect, government regulations and incentive programs could help battery recycling develop to be a more efficient option in the future.

A. Recycling Laws

As the first major wave of electric vehicle batteries will soon reach the end of their life cycle, it is important to analyze the best-case scenario to keep them from being disposed of improperly and to reuse the materials through recycling. Lithium-ion battery recycling programs are accomplished in major part by government legislation that promotes battery-producing companies to have standards such as the extended producer responsibility (EPR), which is widely utilized in different ways around the world.⁸³

Around the world, regulations for lithium-ion battery recycling programs vary, but one of the global leaders in recycling is the U.S.⁸⁴ However, the only federal guidance about the end of the life cycle of lithium-ion batteries is that it is classified under the RCRA as a hazardous material.⁸⁵ Further, the U.S. does not presently have any legislation specifically controlling recycling standards of lithium-ion batteries.⁸⁶ The EPA is expected to solve this gap in legislation quickly as the country moves toward greener alternatives with increasing frequency, by planning to propose new rules that enhance the process of lithium-ion batteries.⁸⁷ This would be an important step in guaranteeing the proper considerations are taken into account when producing and disposing of lithium-ion batteries in the U.S. to promote the efficiency of materials with a reduced environmental impact.

82. *Id.* at 5.

83. CAS Science Team, *Lithium-ion Battery Recycling: Market and Innovation Trends for a Green Future*, AM. CHEM. SOC'Y 3 (Feb. 18, 2025), <https://web.cas.org/marketing/pdf/INSGENENGBRO102412-CAS-Insights-Lithium-Ion-Full-Report-Digital.pdf>.

84. *Id.* at 14.

85. *Id.* at 3.

86. *Id.*

87. *Improving Recycling and Management of Renewable Energy Wastes: Universal Waste Regulations for Solar Panels and Lithium Batteries*, U.S. ENV'T PROT. AGENCY, <https://www.epa.gov/hw/improving-recycling-and-management-renewable-energy-wastes-universal-waste-regulations-solar> (last visited Feb. 10, 2025).

Other major advocates that use lithium-ion battery recycling in practice with specific regulations are the European Union (EU) and China. The EU has used many different legislative schemes to encourage lithium-ion battery recycling. The first piece adopted back in 2018, created an overarching system to support every step of the battery life cycle, including the recycling of lithium-ion batteries.⁸⁸ More recently, the EU passed a more overarching framework that took a “cradle-to-grave” approach by promoting EPR, specifically creating standards for the producers to collect the battery waste and recycle the useful materials from the old batteries.⁸⁹ Specifically, by 2027 the legislation aims to promote transparency of battery producers by utilizing a “digital passport” so that the batteries can be tracked from production until they are recycled.⁹⁰ Similar to the EU, China has passed several laws since 2016 aimed at promoting battery recycling and advancing EPR standards. Under these regulations, the Chinese government requires the manufacturers to recycle the used batteries and promote a circular battery economy.⁹¹ These countries should act as a model for the U.S. to promote more EPR and manufacturer responsibility since the U.S. regulatory scheme for lithium-ion battery recycling is not as developed as these other countries. Without a proper plan in place to recycle lithium-ion batteries, the U.S. may need to turn to a safer alternative to have reduced reliance on lithium extraction and reduce the nation’s environmental impact.

VI. NEED FOR A SAFER SUSTAINABLE ALTERNATIVE

The seemingly unsuccessful effect of the legislation demonstrates that more action must be taken in the emerging field of energy storage to protect the world and its inhabitants from these ongoing issues. Constantly creating new legislation could be an effective way to control the effect that batteries have on the environment, but it is extremely challenging to get the world to agree on its politics. Even when politics concern topics that concern a grave nature, agreements can be broken or withdrawn from. Nevertheless, to ensure that the impact of lithium-ion battery extraction and waste is reduced, a viable alternative should be produced for the open market—specifically, a battery that could conduct similar amounts of electricity but does not contain the same harsh elements or ability to harm.

88. AM. CHEM. SOC’Y, *supra* note 83.

89. *Id.*

90. *Id.*

91. *Id.*

Further, for that alternative to be feasible, especially on the open market where it can make a difference, a substantial amount of research and development needs to take place. While the U.S. government offers many incentives for the development of batteries through the Department of Energy, the focus of that legislation mainly focuses on the progression of electric vehicles.⁹² While focusing on the development of electric vehicles should improve environmental conditions, it is only a smaller part of the picture. The world needs an alternative to lithium-ion batteries that is easier to produce and safer to dispose of so it is necessary for the incentives to reflect that, or else the electricity market will continue to rely on lithium-ion batteries for storage. Thus, around the world, leading engineers work to create a new form of battery to store electricity and make the problems that arise with lithium-ion batteries a thing of the past.⁹³

A. Sodium-Ion Batteries

One alternative to lithium-ion batteries that receives a lot of attention globally, is the invention and advancement of sodium-ion batteries. This progress is noteworthy as the world attempts to reduce its carbon impact as much as possible and utilize the most sustainable practices. Since sodium-ion batteries and the surrounding technology are still being developed, few alternatives could beat lithium-ion batteries' performance. However, due to the rarity and environmental impact of the lithium ore extraction process along with the waste potential, there is a need to develop a new lower-cost battery using an abundant element, and sodium batteries seem to address each of these issues.

First, unlike the costs of extracting lithium for lithium-ion batteries, it is far easier and cheaper to gather the requisite amount of sodium for a battery. Additionally, sodium is a far more accessible and abundant element as the ratio of sodium to lithium in Earth's crust is 23,600 parts per million to 20 parts per million, which means sodium is about 1,000 times more abundant.⁹⁴ That accessibility and abundance lead to a massive price difference between the two elements. Specifically, to mine

92. *Electricity Laws and Incentives in Federal*, U.S. DEP'T OF ENERGY, <https://afdc.energy.gov/fuels/laws/ELEC?state=US> (last visited Apr. 7, 2025).

93. Claudia Lee, *We Rely Heavily on Lithium Batteries—But there's a Growing Array of Alternatives*, BBC (Mar. 20, 2024), <https://www.bbc.com/future/article/20240319-the-most-sustainable-alternatives-to-lithium-batteries>.

94. K.M. Abraham, *How Comparable Are Sodium-Ion Batteries to Lithium-Ion Counterparts?*, AM. CHEM. SOC'Y 3546 (Oct. 23, 2020), https://pubs.acs.org/doi/epdf/10.1021/acsenerylett.0c02181?ref=article_openPDF.

and refine lithium for batteries the cost is about \$15,000/ton while the cost of sodium suitable for batteries is about \$150/ton.⁹⁵

Next, sodium-ion batteries are still being developed, but the energy output appears to compete with that of lithium-ion batteries. Although sodium-ion batteries as of now do not surpass the output of lithium-ion batteries, the close competition continues the conversation for the development of a safer alternative. Since sodium-ion batteries are still in the developmental stages, their true potential is being discovered by scientists, but many sources expect that the energy output of sodium-ion batteries on average could be about 3-4 volts per cell. While that number is currently lower than the output of lithium-ion cells, it is a close second and warrants consideration given its material security and environmental advantages in the market.

One important sign of the desire for growth in the field of alternative energy storage systems is the award of \$50 million to a consortium of energy laboratories over the next five years for the development of sodium-ion storage cells.⁹⁶ This significant investment by the U.S. government shows their inclination to develop an alternative and not depend as much on the more costly, environmentally-impacting lithium-ion batteries.

The successful development of sodium-ion batteries as a viable alternative to lithium-ion batteries would solve the issue of mineral insecurity and global trade tensions, as the U.S. would have a competitive battery with products readily accessible on the domestic market. This trend would lessen the U.S.'s dependence on other countries to export minerals such as lithium or products such as batteries.

B. Legal Obstacles in Developing Sodium-Ion Batteries

Although the invention and testing of an alternative such as sodium-ion batteries is desired by the government and the related communities, various regulatory schemes must be followed to properly create the new form of battery storage. Mainly, the field is managed by laws that regulate the use of federal funds, the caveats that come with it, and the need for batteries to comply with certain laws to comply with requirements to enter the open market.

95. Tom Abate, *A Stanford Battery Based on Sodium May Offer More Cost-Effective Storage Than Lithium*, STANFORD U. (Oct. 9, 2017), <https://news.stanford.edu/stories/2017/10/sodium-based-batteries-cost-effective-lithium>.

96. *A New Era for Batteries: Argonne Leads \$50M Sodium-Ion Innovation Push*, ARGONNE NAT'L LAB'Y (Nov. 21, 2024), <https://www.anl.gov/article/a-new-era-for-batteries-argonne-leads-50m-sodiumion-innovation-push>.

In the development of sodium-ion batteries, groups or universities receive funding from the U.S. government to accomplish the challenge of creating a viable alternative. At the forefront of this movement are schools with advanced engineering programs such as Stanford and Massachusetts Institute of Technology. The main legislation that governs the use of federal funding for the potential invention of new technologies is the Bayh-Doyle Act.⁹⁷ While encouraging the development of new technologies, the act is also used to specifically progress U.S. industries.⁹⁸ Although the government utilizes the Bayh-Doyle Act to promote a developing market with new inventions, the government may make information regarding the technology confidential to avoid misuse or the misappropriation of the information.⁹⁹ Most importantly, the Bayh-Doyle Act allows federal agencies to apply for protection or patent for the technology and grant an exclusive license with or without the inclusion of royalties of the invention in return for the government's investment in the technology.¹⁰⁰ These requirements seem overly intrusive into the process of scientific discovery, but the government is funding the innovative efforts, so it makes sense for the done to owe responsibilities to the donor. The Bayh-Doyle Act protects the government and its investments in American innovation.

Further, the development of sodium-ion batteries should take into account the relevant waste and recycling regulations that apply to other types of batteries. This can be accomplished by guaranteeing the batteries do not have any hazardous material outlined by the RCRA. Additionally, potential manufacturers could assert themselves at the top of the market by being a leader in adherence to EPR standards, even if it is not presently required by legislation. Producers should have the infrastructure in place to recycle the used batteries to reduce the need for more materials and overall battery waste improperly disposed of in landfills.

Given all the potential for a safer, more sustainable alternative electricity storage device, the U.S. government should widely incentivize the development of sodium-ion batteries so they can be used at the commercial and consumer levels. Other than the research scheme outlined previously, there are not too many general incentive programs to produce a new type of electric battery. Presently, the U.S. Department of

97. Christopher M. Cauble, *Unlocking Innovation: Understanding the Impact of the Bayh-Doyle Act*, HARNES IP (July 24, 2024), https://www.harnessip.com/blog/2024/07/24/unlocking-innovation-the-bayh-dole-act/#_edn1; 35 U.S.C. §§ 200-212 (1980).

98. 35 U.S.C. § 204 (1980).

99. 35 U.S.C. § 205 (1980).

100. 35 U.S.C. § 207 (1980).

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Energy does not have many incentive programs that concern the development of alternative electricity storage devices. The programs that do concern batteries are focused primarily on the progression of electric vehicles without considering additional innovations that could affect the field.

VII. CONCLUSION

Given the environmental obstacles created by the extraction, use, disposal, and recycling of lithium-ion batteries in an increasingly electrified world, it is evident that the development of a feasible alternative, such as the sodium-ion battery, is in the best interest of the nation's regulatory framework and the environment. As the world moves closer to accomplishing the implementation of clean energy, there are more factors to consider than just the decrease in the burning of fossil fuels. Depending on rare minerals to create batteries that are required for new inventions and devices will continue to adversely impact the environment even with the implementation of systems to continuously renew and reuse old lithium-ion batteries, and yet the world is still slow to commit to the development of an alternative. The legal framework, especially in the U.S. does not keep up with the constant innovations and as a result, new electrified devices are invented without much consideration about the evolution of the batteries that power those devices.