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The Electrifying Problem of Used Lithium Ion Batteries: Recommendations for Lithium Ion Battery Recycling and Disposal

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I. INTRODUCTION

The number of electric vehicles (EVs) on the road is rising and projected to greatly increase in the coming years. Post-application vehicle battery packs are estimated to rise from 1.4 million to 6.8 million by 2035.[1] The preferred battery choice for EVs is lithium ion batteries (LIBs). Recycling these batteries is imperative to protect human health, the environment, and the natural supply of lithium.

Presently, only 3% of LIBs are being recycled and lithium recovery is negligible.[2] At this rate, lithium demand will outstrip supply in 2023.[3] While potential fire hazards in transportation are regulated by the U.S. Department of Transportation (DOT), there are no regulations regarding recycling of large-format LIBs. Since lithium battery packs are assumed to have a life cycle equivalent to the life of a vehicle, the majority of battery packs will not end their useful life in large numbers for another ten years. A study funded by the U.S. Department of Energy (DOE) projects that with a low estimate service life of five years, there will be 1,423,000 discarded battery packs in 2020 in the United States.[4] The upper end estimate of a ten-year lifetime decreases this number to 295,000.[5] Comprehensive legislation and safety laws are greatly needed now to prepare for this wave of waste.

While states can be an important catalyst for federal action, the car industry ultimately needs federal regulation. The history of the Clean Air Act (CAA) exemplifies that automobiles are a national market and that the industry prefers uniform, federal standards. California

[1] S. Rohr et al., 14th Global Conference on Sustainable Manufacturing, *Quantifying Uncertainties in Reusing Lithium-Ion Batteries from Electric Vehicles*, 603 (Oct. 2016).
[2] Alexandru Sonoc. et al., 22nd CIRP Conference on Life Cycle Engineering, *Opportunities to Improve Recycling of Automotive Lithium Ion Batteries*, 752 (2015).
[3] *Id.*
[4] Chaitanya K. Narula et al., FINAL REPORT: ECONOMIC ANALYSIS OF DEPLOYING USED BATTERIES IN POWER SYSTEMS 2-3 (June 2011), cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=3174.
[5] *Id.*

preceded the federal government in regulating vehicle efficiency and tailpipe emissions. In 1959, California enacted the first emission control requirements and, in 1966, passed the first tailpipe emission standards for new cars.[6] Congress then passed the Motor Vehicle Air Pollution Control Act in 1965 which laid the groundwork for the CAA.[7] Auto manufacturers supported federal regulation because of growing concern that California and other states would enact more aggressive regulation, resulting in multiple compliance standards around the country. This is problematic because automobiles are sold nationally and can easily cross state lines. In 1970, Congress passed the CAA which sets nationwide standards for air pollution emissions from mobile sources and preempts state regulation.[8] California is the one exception and may apply for a waiver under section 209.[9] Other states are permitted to follow either federal or California's more stringent standards under section 177.[10] The CAA illustrates that federal regulation would offer uniformity for LIB recycling and therefore would be preferable to industry.

Additionally, the federal government is better suited than states to regulate LIB recycling because the Commerce Clause of the Constitution gives Congress power over interstate and international trade.[11] As a result, states are unable to regulate export of waste in a way that discriminates against interstate commerce.[12] This is a problem for electronic waste (e-waste) and could be a problem for LIBs if recycling remains unprofitable and exporting waste becomes the preferred waste management strategy.

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[6] Holly Doremus et al., *Environmental Policy Law: Problems, Cases, and Readings* 697 (Robert C. Clark et al., eds., 6th ed. 2012).
[7] *Id.*
[8] *Id.* at 633, 696.
[9] *Vehicle Emissions California Waivers and Authorizations*, U.S. ENVTL. PROTECTION AGENCY, https://www.epa.gov/state-and-local-transportation/vehicle-emissions-california-waivers-and-authorizations (last visited Nov. 12, 2017).
[10] *Id.*
[11] U.S. Const. art. I, §8, cl. 3.
[12] Hannah G. Elisha, Comment, *Addressing the E-Waste Crisis: The Need for Comprehensive Federal E-Waste Regulation within the United States*, 14 Chap. L. Rev. 195, 216 (2010).

The federal government thus has a potentially critical role in establishing and sustaining a LIB recycling system and should take the following actions: establish a research program focused on LIB recycling processes, pass legislation modeled after lead acid battery programs providing flexible regulatory options for recycling, and incorporate extended producer responsibility (EPR).

EPR shifts the cost of recycling from governments in charge of waste management to producers by having battery producers internalize the cost of recycling. So far, EPR has been enacted only on the state level and has not been adopted into federal policies. Since automobiles represent a nationwide market, federal EPR regulations should be adopted for LIBs. The European Union (EU) has enacted a union-wide EPR scheme for LIBs and automotive vehicle batteries. As such, the EU provides a useful case study for the United States.

While standardizing LIB battery compositions would allow for streamlined and easier recycling, standardization has the potential to stifle technological innovation and would likely be politically infeasible. Automobile manufacturers are very secretive when it comes to their battery compositions and would lobby strongly against any mandates to standardize designs. Rather than promote standardization, the federal government should focus on EPR, researching recycling technologies, and enacting flexible regulations. This paper explores the feasibility of these policy recommendations through analysis of federal and California government actions, as well as responses by the EU and industry.

II. BACKGROUND ON LITHIUM ION BATTERIES AND THE NEED TO RECYCLE

In 1991, LIBs were first commercialized by Sony.[13] The demand for LIBs has grown rapidly, largely because of increased demand for portable electronic devices. The use of LIBs in electric and plug-in hybrid vehicles began in 2011 with the introduction of the Nissan Leaf and Chevy Volt.[14]

LIBs have become the preferred battery choice for electronic devices and EVs because they have characteristics that are conducive to rechargeable, portable systems. LIBs have lightweight components, high energy capacity, a high ratio of voltage per cell, favorable discharge resistance, capability to work through a significant number of regeneration cycles and temperatures, and relatively low environmental impacts.[15] While hybrid and EVs have relied on nickel metal hydride (NiMH) batteries in the past, LIBs are expected to dominate the market moving forward. The International Energy Agency projects that the annual production of LIBs for EV use will rise to 100 million in 2050.[16] This growing market will greatly increase demand on natural lithium supplies and create a significant amount of waste that needs to be properly disposed of rather than sent to landfills.

a. Lithium Scarcity

While lithium is a relatively plentiful naturally occurring material, supplies are concentrated in select regions of the world. South America retains the majority of the global lithium supply. Chile holds approximately 76% of the world's currently accessible lithium reserves, while Argentina and Australia are the next largest suppliers with a combined total of

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[13] Harrison Lebov, Note, *A Darker Shade of Green: Hazards Associated with Lithium Ion Batteries*, 17 J. HIGH TECH. L. 78, 81 (2016).
[14] Lew Fulton, et al., *Three Revolutions in Urban Transportation*, U.C. DAVIS INST. OF TRANSP. STUD. 1, 8 (2017).
[15] J. Ordonez et al., *Processes and Technologies for the Recycling and Recovery of Spent Lithium-Ion Batteries*, 60 RENEWABLE AND SUSTAINABLE ENREGY REVIEWS 195, 196 (2016).
[16] Sonoc, *supra* note 2, at 752.

14%.[17] Recent reports suggest Bolivia may retain the world's largest lithium supply, but the reserve is located below a scenic region that the Bolivian government has vowed to protect.[18] In addition to being limited to a few regions of the world, mining lithium is costly and environmentally harmful. Finding a large lithium deposit that is cost effective to mine is a key concern. Mining and extraction are also accompanied by significant environmental impacts. Smelting, to obtain copper, nickel and cobalt- all metals contained in LIBs- emits sulfur dioxide, which is one of six criteria air pollutants with a national air ambient quality standard set by the U.S. Environmental Protection Agency (EPA) .[19]

Because lithium deposits are located outside the United States, competition among miners and changing international relations could increase LIB prices in the United States. Since LIBs currently make up a large portion of an EV's cost, an increase in the price of batteries could retard acceptance of EVs. Recycling LIBs to recover lithium and other precious metals would enable the United States to reduce dependence on raw materials and retain price control in a self-sustaining market.

b. Environmental and Health Impacts

i. Environmental Hazards

LIB's design, particularly the choice of active material for the cathode, changes human health, toxicity and environmental impacts due to the processing of materials, initial metal extraction, and energy use. A study conducted by the EPA found that battery chemistries that use more aluminum showed a higher potential for ozone depletion compared to nickel cobalt

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[17] Andrew W. Eichner, Note, *More Precious than Gold: Limited Access to rare Elements and Implications for Clean Energy in the United States*, U. III. J.L. TECH. & POL'Y 257, 265-66 (2012).
[18] M.C. McManus, *Environmental Consequences of the Use of Batteries in Low Carbon Systems: The Impact of Battery Production*, 93 APPLIED ENERGY 288, 299 (2012).
[19] Linda Gaines, *The Future of Automotive Lithium-Ion Battery Recycling: Charting a Sustainable Course,* SUSTAINABLE MATERIALS AND TECH., Nov. 2014, at 1.

manganese lithium ion (Li-NCM) batteries.[20] However, Li-NCM batteries are not necessarily more environmentally friendly; Li-NCM batteries require twice as much primary energy and contain rare metals which have significant non-cancer and cancer toxicity potential.[21]

Environmental hazards resulting from LIBs should be considered when implementing waste and recycling policies. LIBs contain a high percentage of dangerous heavy metals: from the 4,000 tons of LIBs collected in 2005, 1,100 tons of heavy metals and more than 200 tons of toxic electrolytes were generated.[22] Potentially toxic materials in LIBs are copper, nickel, lead and organic chemicals, such as toxic and flammable electrolytes.[23] Accordingly, LIBs are classified as Class 9 miscellaneous hazardous materials.[24] Transportation of these materials is regulated under Title 49 of the Code of Federal Regulations (CFR). Hazardous materials are defined by the Secretary of Transportation as those "capable of posing an unreasonable risk to the health, safety, and property when transported in commerce."[25] Overheating LIBs pose a risk of fire, particularly in aviation transportation. Regulations subject LIBs to complex inspection, testing, packaging, labeling, recordkeeping, and notification requirements.[26]

ii. <u>Health Hazards</u>

Lithium additionally poses human health risks once it enters the human system. Lithium can be absorbed and accumulated in edible plants and thus enter the food chain.[27] Health risks include genetic toxicity, reproductive toxicity and gastrointestinal toxicity. Genetic toxicity from

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[20] U.S. ENVTL. PROTECTION AGENCY, *Application of Life-Cycle Assessment to Nanoscale Technology: Lithium-ion Batteries for Electric Vehicles* 1, 102 (2013).
[21] *Id.*
[22] Ordonez, *supra* note 15, at 195.
[23] Daniel Hsing Po Kang et al., *Potential Environmental and Human Health Impacts of Rechargeable Lithium Batteries in Electronic Waste*, ENVTL. SCI. & TECH., 5495, 5495 (2013).
[24] Gaines, *supra* note 19, at 1.
[25] Lebov, *supra* note 13, at 87.
[26] Jonathan Todd et al., *Lithium Batteries in Flight: Risks and Regulations*, LAW 360, Dec. 20, 2016, at 2.
[27] Soodabeh Saeidnia and Mohammad Abdollahi, *Concerns on the Growing Use of Lithium: The Pros and Cons*, IRAN RED CRESCENT MED. J., 629-632 (2013), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3918183/.

lithium can disturb invertebrate development. A study that exposed pregnant mice to high doses of lithium resulted in smaller litters, both in size and weight, and offspring born with defects.[28] Lithium exposure can also affect reproduction, resulting in accelerated incidence of Ebstein's anomaly in babies born from mothers who receive lithium therapy, risk of fetal cardiovascular malformation and reversible impotency in men.[29] Chronic lithium exposure and therapy can cause gastrointestinal problems including vomiting and diarrhea.[30]

iii. Legal Framework to Address Hazards

The Resource Conservation and Recovery Act (RCRA) regulates the generation, transportation, treatment, storage and disposal of hazardous solid wastes.[31] To be regulated under RCRA, a waste must be both "solid" and "hazardous" under specific statutory definitions. A solid waste is considered hazardous if:

> because of its quantity, concentration or physical, chemical, or infectious characteristics may cause or significantly contribute to an increase in mortality or…serious…injury or pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.[32]

A hazardous waste may be specifically listed by the EPA or exhibit characteristics of ignitability, corrosivity, reactivity, or toxicity under prescribed testing conditions.[33] While lithium is not listed as a hazardous material, LIB characteristics may trigger RCRA regulation.

A study of rechargeable LIBs in portable electronics using the Toxicity Characteristics Leaching Procedure (TCLP) concluded LIBs should be characterized as hazardous waste as a result of excessive lead levels. [34] TCLP is the process outlined in RCRA regulations to determine

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[28] *Id.*
[29] *Id.*
[30] *Id.*
[31] Doremus, *supra* note 6, at 478.
[32] 42 U.S.C. §6903 (5) (A-B).
[33] Doremus, *supra* note 6, at 478.
[34] Kang, *supra* note 24 at 5499; *see also* 40 C.F.R. §261.24 (a).

whether a material is hazardous because of its toxicity.[35] All batteries tested were found to be hazardous under California regulations because they exhibited excessive levels of cobalt, copper, and, in some instances, nickel.[36] Because some components of LIBs are difficult to break down, if disposed in municipal waste landfills, they may contaminate the soil and underground water.[37] The study identified metals- copper, cobalt, nickel and lead- that would leach concentrations exceeding regulatory limits under simulated landfill conditions.[38] Additionally, incinerating LIBs releases toxic gases that contaminate the air.[39]

Under RCRA, a waste generator is responsible for determining whether its waste is a characteristic hazardous material.[40] Testing EV LIBs is necessary since lithium is not a listed waste under RCRA and the studies discussed above tested portable electronic batteries rather than large-format vehicle LIBs. Whether a manufacturer's LIB is subject to RCRA is a key issue as many detailed regulations apply to the handling, treatment, storage and disposal of hazardous waste.[41]

c. Challenges to Recycling

While the need for recycling is clear, the process of recycling on a large-scale is complicated by certain LIB characteristics, including cost, infrastructure, differing designs and LIB compositions. The first problem is that current recycling processes recover far less lithium than automotive LIB manufacturers need.[42] Since recycling processes do not recover an adequate amount of materials and lithium has relatively low value, the cost of recycling exceeds benefit.

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[35] Kang, *supra* note 24 at 5496.
[36] *Id.*
[37] Ordonez, *supra* note 15, at 196.
[38] Kang, *supra* note 24, at 5502.
[39] *Id.*
[40] 40 C.F.R. §262.11(c).
[41] *See generally* 42 U.S.C. §§ 3004, 3005.
[42] Sonoc, *supra* note 2, at 756.

As a result, no infrastructure currently exists for disposing or recycling large LIBs and companies do not have an incentive to collect and recycle their batteries.[43]

A second challenge stems from LIBs being an emerging technology. Chemical compositions of the active materials used in LIBs, particularly in the cathode materials, vary by manufacturer.[44] The most common cathode material is lithium cobalt oxide, but other combinations of nickel, manganese and aluminum can be used to lower raw material cost and increase battery performance.[45] Different compositions of batteries require different types of recycling processes and hinder the adoption of a uniform system.

Presently, there are a variety of recycling processes under consideration for large-scale LIB resource recovery: pyrometallurgical (smelting), cryogenically cooling, hydrometallurgical, and direct recycling. Smelting processes recover basic elements or salts.[46] Using high temperatures, organic materials, including the electrolyte and carbon anodes, are burned as fuels or reductants and recovered valuable materials are sent for refining.[47] The remaining materials, including lithium, are contained in the slag which can be used as an additive in concrete.[48] In contrast, direct recovery processes recover battery-grade materials by separating active materials and metals through a combination of physical and chemical processes.[49] Direct recovery is a low-temperature process that requires minimal energy use.[50]

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[43] Philip Hailey and Keith Kepler, DIRECT RECYCLING TECHNOLOGY FOR PLUG-IN ELECTRIC VEHICLES LITHIUM ION BATTERY PACKS, 3 (March 2015), http://www.energy.ca.gov/2016publications/CEC-500-2016-016/CEC-500-2016-016.pdf.
[44] Gaines, *supra* note 19, at 5.
[45] *Id.*
[46] U.S. DEP'T OF ENERGY, *Recycling Batteries*, BATTERIES FOR HYBRID AND PLUG-IN ELECTRIC VEHCILES, https://www.afdc.energy.gov/vehicles/electric_batteries.html (last visited Nov. 4, 2017).
[47] *Id.*
[48] *Id.*
[49] *Id.*
[50] *Id.*

The specific design of a LIB can determine whether a certain recycling process is economical. For example, smelting is economical for batteries with cobalt and nickel but not for manganese or lithium ion phosphate cathodes.[51] Lack of consensus on which recycling process is most efficient, in addition to rapidly changing designs, makes it difficult to achieve an efficient recycling program. However, these challenges may be overcome with proper government participation and regulation.

III. THE CURRENT AND POTENTIAL ROLE OF THE FEDERAL GOVERNMENT

Regulation of LIB recycling is needed at the federal level. While the United States has yet to establish a specific policy regarding LIB recycling, existing policies suggest the potential for a national LIB program. These policies include grants for LIB recycling facilities, legislation directed at batteries and LIB safety, federal studies, and the lead acid battery recycling program.

a. Grants

In 2009, the DOE granted $9.5 million to Toxco, since renamed Retriev, a company based in Anaheim, California, to build America's first recycling facility for vehicle LIBs.[52] DOE's matching funds had the purpose of promoting sustainable hybrid and EV batteries. The recycling facility is located in Lancaster, Ohio and is an anticipated future site for advanced large-format LIB recycling. The Vice President of Toxco's Ohio operation, Ed Green, stated, "The new plant will let us continue to recover resources, such as nickel and cobalt, for use in manufacturing new batteries for the U.S. market."[53]

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[51] Gaines, *supra* note 19, at 5.
[52] Eichner, *supra* note 17, at 275.
[53] Francis Richards, *An Uncertain Future for Recycling Electric Vehicle Batteries*, POWER ELECTRONICS (Feb. 1, 2012), http://www.powerelectronics.com/markets/uncertain-future-recycling-electric-vehicle-batteries.

Despite being an established company in the battery recycling business, Retriev has been cited for nine Occupational Health and Safety Administration (OSHA) violations, including eight repeat violations, and a $74,250 fine for exposing employees to lead and cadmium in amounts that exceeded the legal permissible exposure limit.[54] This type of exposure can damage the central nervous system, reproductive system and cause other health problems.[55] Many of the violations have not been addressed since OSHA's 2012 report which identified and cited Toxco for the same hazards.[56] Safety hazards that accompany EV and hybrid vehicle battery recycling need to be addressed to ensure a safe and sustainable system.

b. Legislation

While Congress has passed legislation encouraging the adoption of EVs, it has largely ignored the EOL battery stage. In 1976, Congress passed the Electric and Hybrid Vehicle Research, Development, and Demonstration Act.[57] This Act acknowledged that the Nation's dependence of foreign oil needed to be reduced and listed as its purposes to advance research and demonstrate the economic and technological practicability of EVs.[58] The Act did not discuss the EOL stage and has not been amended to address the battery waste issue.

In 2016, the Lithium Battery Safety Act was introduced to Senate but was not reported out of committee.[59] This Act focused on LIBs in transport and would have amended the Federal Aviation Administration (FAA) Modernization and Reform Act of 2012 by repealing the ban on DOT regulations that are more stringent than international standards.[60] It would have also created

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[54] Dan Gearino, Lancaster Battery Recyclers Facing OSHA Fines, THE COLUMBUS DISPATCH (Aug. 28, 2015 6:14 AM) http://www.dispatch.com/content/stories/local/2015/08/27/battery-recycler-OSHA-violations.html.
[55] *See* 57 FED. REG. 42102 § 5 (Sept. 14, 1992); *see also Health Effects*, U.S. DEP'T OF LAB. (last visited Nov. 1, 2017), https://www.osha.gov/SLTC/lead/healtheffects.html.
[56] Gearino, *supra* note 55.
[57] 15 U.S.C. § 2501 (1976).
[58] *Id.*
[59] S. 2528, 114th Cong. (2016).
[60] *Id.*

a LIB safety working group to promote and coordinate efforts related to the safe manufacture, use, and transport of LIBs.[61] Unlike recycling, LIB transportation is regulated by the United States government. The DOT regulates the shipment, classification, and packaging of live or discharged LIBs.[62] Though the Safety Act focused on transportation, it is promising that Congress recognizes the need to regulate LIBs for environmental impacts and safety hazards.

Legislation focused more generally on batteries and electronics provides a useful framework for considering how the United States might address LIB waste. The Responsible Electronics Recycling Act, introduced in the House of Representatives in 2011 but never enacted, is a good example of legislation the United States should adopt moving forward to generate research on LIB recycling processes. This act would have amended the Solid Waste Disposal Act to restrict e-waste exports for a wide variety of electronic devices, including televisions, digital cameras and projectors, audio equipment, portable gaming systems, computers, and telephones. Motor vehicle parts, however, were specifically exempted. Such restrictions can incentivize the development of recycling methods domestically.

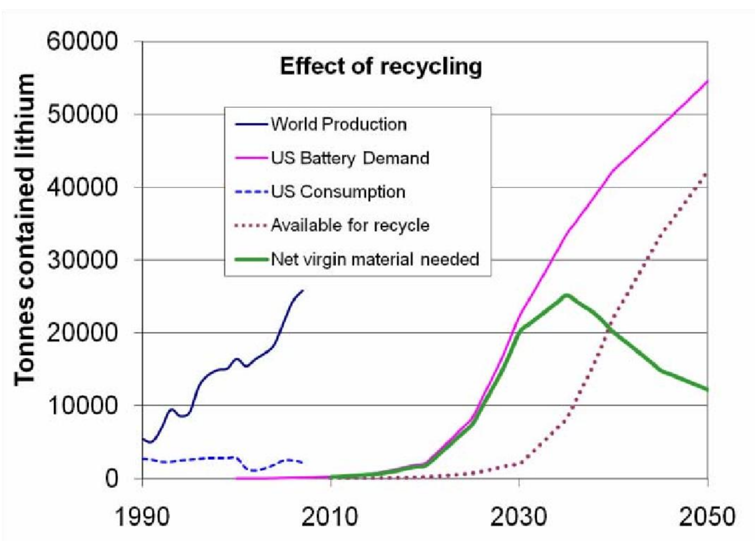
The Act would have also directed the Secretary of Energy to establish a Rare Earths Recycling Research Initiative, a competitive research program, to increase research into recycling rare earth metals in electronic devices. Grants would have been awarded to applicants for research projects in the following categories: (1) safe removal, separation, and recycling of rare earth metals in electronics, (2) technology, component, and material design of electronics more suitable for disassembly and recycling, and (3) collection, logistics, and reverse supply chain optimization for the recycling of rare earth metals in electronics.[63] The bill listed seventeen

[61] *Id.*
[62] *See* 49 C.F.R. § 173.185 (j).
[63] *Id.*

chemical elements but also provided the Secretary the ability to identify other elements found to be rare or in critical supply.[64] Since a couple of challenges for LIB recycling are rapidly changing designs and safety hazards accompanied with dismantling, a similar research initiative aimed solely at LIBs would generate essential information.

c. Studies

In 2013, the EPA conducted a joint study with the DOE, LIB industry, and academics. This study was the first life cycle analysis to use data provided by LIB suppliers, manufacturers, and recyclers and was conducted to identify the materials or processes that most impact public health and the environment.[65] While not focused on the EOL stage, the EPA recognized the importance of curtailing the extraction of raw materials to preserve resources and reduce environmental impacts.[66] The chart below summarizes the EPA's findings on the upper-end potential effect of recycling on lithium demand.[67]



[64] *Id.*
[65] U.S. ENVTL. PROTECTION AGENCY, *supra* note 20, at 1.
[66] *Id.* at 11.
[67] *Id.* at 56.

The EPA noted that there should be an incentive to recycle based on the value of recovered materials, including cobalt, nickel, lithium, and organic chemicals and plastics.[68] In its recommendations, the EPA discussed the need to increase battery lifetime and to reduce cobalt and nickel use because of their relative toxicity.[69] With respect to recycling processes, the EPA found low-temperature recycling technologies to be most beneficial since they increase recovery, require less energy, and result in less material transformation.[70]

d. Case Study: Lead Acid Battery Recycling

The United States' successful lead acid battery recycling program provides a valuable case study for LIBs because it demonstrates that large, automotive batteries can be recycled profitably on a national scale. Today, 98% of lead acid batteries are collected and recycled in the United States.[71] Factors that contribute to the success of this program include flexible regulations, profitability, a simple recycling process, and uniformity among almost all manufacturers in use of raw materials: lead, lead oxide and sulfuric acid.[72] While LIBs and lead acid batteries have key differences, there are many aspects of lead-acid battery recycling that can be adopted into a successful LIB recycling program.

i. <u>Laws and Regulations</u>

The laws and regulations surrounding lead acid battery recycling have enabled manufacturers and recyclers to work together in a profitable and transparent system. Lead acid batteries are subject to RCRA because they exhibit toxicity levels of lead that are characteristic of hazardous waste. To encourage recycling, the EPA has prohibited export and provided two

[68] *Id.*
[69] *Id.* at 106.
[70] *Id.* at 12-13, 102.
[71] Sonoc, *supra* note 2, at 756.
[72] Gaines, *supra* note 19, at 4.

alternative management standards that exempt battery recyclers from RCRA regulations: 40 CFR 266, subpart G, and the Universal Waste Regulations under 40 CFR 273, subpart G.[73]

40 CFR 266 outlines exemptions from certain RCRA regulations for reclaimed lead acid batteries. This scheme is organized in a chart by how the battery will be reclaimed and the actor's role in the process. Exemptions from hazardous waste regulations under RCRA depend on the technique used for reclamation (for example, whether the battery will be reclaimed through regeneration) and whether one stores, transports, exports, or imports batteries before or after reclamation.[74] The section states that lead acid battery reclaimers may alternatively choose to handle their batteries under the Universal Waste Regulations.[75]

The Universal Waste Regulations were created by the 1996 Mercury-Containing and Rechargeable Battery Management Act to standardize a variety of state regulations on collecting and recycling batteries into a national program.[76] These regulations provide permissible treatment options to prevent toxic releases into the environment and prohibit handlers of universal waste from disposing or diluting lead acid batteries in any other way.[77] Generators storing batteries that will be reclaimed by regeneration- i.e. by replacing the electrolyte- are exempt from RCRA regulations; however, if the battery is to be reclaimed by any other method, generators are subject to the applicable land disposal restriction in 40 CFR part 268.[78] Each battery must be specifically labeled with the words "Universal", "Waste", or "Used Battery" and

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[73] James Griffin, RCRA Options for Recycling Lead-Acid Batteries, LION TECHNOLGIES (Sept. 25, 2012), https://www.lion.com/lion-news/september-2012/rcra-options-for-recycling-waste-lead-acid-batteri.
[74] *Id.*
[75] *Id.*
[76] *The 1996 Battery Act: The Fulfillment of a Dream*, CALL 2 RECYCLE, https://www.call2recycle.org/1996-battery-act/.
[77] Griffin, *supra* note 75.
[78] *Id.*

employees must be trained in how to properly handle lead-acid batteries in the event of fire, explosions, or releases.[79]

Export of lead acid batteries is prohibited under RCRA unless the exporter has submitted a notice to the EPA requesting approval, demonstrates written acceptance from the receiving country, complies with regulations set forth in 40 CFR 262 Subpart E or H, and can prove shipments have the importing countries' consent.[80] Notices to the EPA are expected to be detailed and include information on the specific recycling facility that will be accepting the batteries, maximum amount of batteries proposed for export and which port of entry will be used in the importing country.[81] These regulations are in place to avoid exporting battery waste to disadvantaged countries for treatment in illegal or hazardous ways.

ii. Lead Acid Battery Recycling: Successes and Shortcomings

Recycling lead acid batteries can be very profitable. Companies such as RSR Technologies and its parent company ECO-BAT have revenues exceeding $1 billion per year globally.[82] The process is profitable because recycled lead, taken to its elemental form and purified, is universally known and accepted to be a high-quality product.[83] As a result of the profitability and high rate of recycling, lead-acid batteries have become one of the cheapest batteries on the market in terms of dollar per watt-hour.[84]

Recycling processes for lead acid batteries are evolving to become more environmentally friendly. In July 2016, AquaRefinery, a startup company based in Alameda, California, opened a

[79] *Id.*
[80] RCRA Online, *Export of Used or Spent Lead Acid Batteries for Recycling*, U.S. ENVTL. PROTECTION AGENCY (Sept. 12, 2011), https://yosemite.epa.gov/osw/rcra.nsf/ea6e50dc6214725285256bf00063269d/b9eb82c9732701098525793e005b91f0!OpenDocument.
[81] *Id.*
[82] Hailey, *supra* note 43, at 5.
[83] Gaines, *supra* note 19, at 4.
[84] Hailey, *supra* note 43, at 5.

battery recycling facility in Nevada that uses a new electrochemical process to recycle lead acid batteries from cars.[85] This method has many environmental benefits over the traditional method of smelting: it releases no arsenic or lead, sends no slag to landfills, and produces about 1/5 of the greenhouse gas emissions and less than 1% of the sulfur dioxide.[86] This is a particularly important development following the closure of the Exide Technologies plant in Los Angeles County.

Exide Technologies, one of two smelters on the West Coast, permanently closed in 2015 after releasing dangerously high levels of lead and arsenic into the air.[87] Exide negotiated with the U.S. Attorney's Office to avoid criminal prosecution. In return, Exide acknowledged its criminal conduct, including the illegal storage and transportation of hazardous waste, and promised to shut down, demolish, and clean its 15-acre battery recycling plant.[88] This marks the end of a long fight as Exide has been contaminating groundwater and air quality for decades. High levels of lead, arsenic, cadmium and other toxic metals were released into soils and groundwater, affecting the surrounding areas.[89] The South Coast Air Quality Management District found Exide's arsenic emissions endangered 110,000 residents in nearby communities.[90] Exide does not represent an isolated occurrence. Lead acid battery recycling is one of the worst polluting industries worldwide and, because lead is a highly toxic metal, improper treatment can have serious environmental effects. If one lead acid battery is disposed of incorrectly in a

[85] David R. Baker, *In the Shadow of the Gigafactory, a New Way to Recycle Batteries*, S.F. CHRON. (July 28, 2016 5:54 PM), http://www.sfchronicle.com/business/article/In-the-shadow-of-the-Gigafactory-a-new-way-to-8529299.php.
[86] *Id.*
[87] *Id.*
[88] Tony Barboza, Exide Closing Vernon Plant to Avoid Criminal Prosecution, L.A. TIMES (Mar. 11, 2015 10:59 PM), http://www.latimes.com/local/crime/la-me-0312-exide-20150312-story.html.
[89] *Id.*
[90] *Id.*

municipal solid waste (MSW) system, it can contaminate 25 tons of waste and prevent the recovery of organic resources.[91]

iii. A Comparison of Lead Acid Batteries and Lithium Ion Batteries

Key differences between lead acid batteries and LIBs make an identical recycling program infeasible. In contrast to standard lead acid batteries, LIB designs are rapidly evolving. LIBs also have a wider variety of materials in each cell: lead acid batteries have a relatively small number of lead plates in a single plastic case whereas a LIB pack may have 100 or more individual cells (some reports state Tesla's LIB battery packs contain around 5,000 cells) connected into modules and assembled into a battery pack with control circuits attached to each cell.[92] LIBs also sometimes contain a thermal management system.[93]

The composition of LIBs changes the economic return of recycling since elements have different values once recovered. Despite being 100% recyclable, recycled lithium can cost up to five times more than mined lithium.[94] While lithium can be extracted from the slag produced from LIB recycling, it is currently not profitable to do so.[95] Instead, the slag is sold to non-automotive industries, including construction, pharmaceuticals, ceramics, and glass.[96] Other materials in LIBs, such as cobalt and nickel, are more valuable than lithium but as LIBs evolve to become cheaper to produce, these more valuable materials are being used in increasingly

[91] Salman Zafar, *The Problem of Used Lead Acid Batteries*, ECO MENA (July 30, 2016), https://www.ecomena.org/managing-lead-acid-batteries/.
[92] Gaines, *supra* note 19, at 5.
[93] *Id.*
[94] *The Lithium Battery Recycling Challenge*, WASTE MGMT. WORLD (Jan. 08, 2011 9:30 PM), https://waste-management-world.com/a/1-the-lithium-battery-recycling-challenge.
[95] *Id.*
[96] Id.

smaller quantities.[97] In contrast, lead acid batteries are 70% lead by weight and produce a quality product equivalent to primary mined lead.[98]

A further difference is that lead acid batteries are small and easily removed from under the hood of a car. LIBs are larger and vary in shape and location in vehicles.[99] For this reason, LIB removal will likely be limited to the industrial sector, increasing the need for health and safety regulations for workers removing the batteries.

Despite these differences, certain aspects of lead acid battery recycling demonstrate the potential for a nationwide LIB recycling program. First, there is consumer and industry awareness that automotive batteries need to be recycled because of their resource value and potential environmental harm. Second, infrastructure is in place to collect and recycle large volumes of lead acid batteries. There is also a regulatory scheme in place that could translate into a LIB recycling program. The flexible regulatory options and prohibition on export offered as exemptions from RCRA would promote LIB recycling.

IV. CALIFORNIA

Though California has yet to pass legislation specifically regarding LIB recycling, it has enacted EPR policies for lead acid batteries and portable batteries. In addition, California has acknowledged the need to recycle LIBs in recent reports and action plans.

a. Lead Acid Battery Recycling Act of 2016

California's Lead Acid Battery Recycling Act of 2016 encompasses an EPR-like scheme for lead acid batteries. The Lead Acid Battery Recycling Act applies to lead acid batteries

[97] John Peterson, *Why Advanced Lithium Ion Batteries Won't Be Recycled*, ALT ENERGY STOCKS, (May 16, 2011), http://www.altenergystocks.com/archives/2011/05/why_advanced_lithium_ion_batteries_wont_be_recycled/.
[98] *See* Peterson, *supra* note 99; *see also Lead Recycling*, INT'L LEAD ASS'N, https://www.ila-lead.org/lead-facts/lead-recycling (last visited Nov. 26, 2017).
[99] *Id.*

weighing more than 5 kilograms and includes starting batteries and motive power batteries used in vehicles.[100] Existing law prohibits the disposal of lead acid batteries in solid waste facilities and requires dealers to accept lead-acid batteries from consumers in exchange for a new battery. This Act revises the law to require dealers to accept, at point of transfer, used lead acid batteries and establishes a "battery fee" for both the consumer and manufacturer.[101]

The new financing scheme imposes a non-refundable "California battery fee" and a refundable deposit for each lead-acid battery purchased from a dealer.[102] If the purchaser returns a lead acid battery of the same type and size to the retailer within 45 days of the sale, the deposit is repaid.[103] Every dealer is required to collect the battery fee, currently \$1/battery but raised to \$2/battery on April 1, 2022, at time of sale and may retain 1.5% of the fee as reimbursement for any costs associated with collecting the fee.[104] The remainder of the fee is paid to the State Board of Equalization (BOE). Manufacturers are also charged a \$1 battery fee for every lead acid battery it sells at retail to a dealer, wholesaler, distributor, or person in California.[105]

The BOE uses the collected money for refunds and reimbursements and to create a "Lead Acid Battery Cleanup Fund" within the State Treasury.[106] The Cleanup Fund can be utilized to investigate and conduct site evaluations, cleanups, remedial actions, removals, monitoring, and response actions at areas reasonably suspected to have been contaminated by lead acid battery recycling facilities.[107] The collection from manufacturers is used, in part, to reduce the

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[100] CAL. HEALTH & SAFETY § 25215.1 (e) (Deering 2016).
[101] *Id.* at § 25215.2 (a).
[102] *Id.* at § 25215.2 (c).
[103] *Id.*
[104] CAL. A.B. §2153 (2016).
[105] CAL. HEALTH & SAFETY § 25215.35.
[106]*Id.* at § 25215.5 (a).
[107] *Id.*

manufacturer's share of liability in tort actions related to hazardous substance releases from lead acid recycling facilities.[108]

The Act also sets forth requirements for labeling and information generation. After July 1, 2017, manufacturers are required to place a recycling symbol and the words "Pb" or "lead", "return" and "recycle" on all replacement batteries sold in state.[109] The Act increases information about where batteries are being sold and collected by requiring dealers and manufacturers of lead-acid batteries to register with the BOE.[110]

A cleanup fund, labeling requirements related to the recyclability of a battery, and information generation are all tools that would be helpful in enacting LIB recycling legislation. While consumers may not be able to easily remove LIBs from their cars, they could be charged a battery fee when they purchase their EV or hybrid vehicle. Labelling LIBs as recyclable and including terms such as "Lithium-ion" would address the current issue of LIBs being facially indistinguishable from lead acid batteries. Accidental inclusion of LIBs in secondary lead smelter input streams has resulted in fires and explosions.[111] Labelling would establish a way to easily sort LIBs from lead acid batteries which would enable safer and more effective recycling of both types of automotive batteries. Lastly, information generation would allow the State to know where LIBs are being sold and returned, which would be useful in determining the best locations for recycling facilities.

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[108] *Id.* at §2521.56 (b).
[109] *Id.* at §25215.65.
[110] *Id.* at §25215.45 (b).
[111] Gaines, *supra* note 19, at 6.

b. Extended Producer Responsibility and E-Waste

California, along with seven other states, has enacted EPR laws for rechargeable batteries.[112] California's law, codified in Public Resources Code sections 42451-42456, states that all small, non-vehicular rechargeable batteries, including LIBs, should not be disposed in MSW and establishes a "comprehensive and innovative" system for recycling and disposing of used batteries by assigning responsibility for costs associated with handling, recycling, and disposing of rechargeable batteries to producers and consumers rather than state and local governments.[113] The sections state that manufacturers have the flexibility to partner with other manufacturers and businesses to establish a recycling program and that the resulting recycling program should be convenient for consumers.[114]

California provides just one example of a state enacted EPR law. Over the past twenty years, states have enacted more than 70 EPR laws with 40 laws passed since 2008.[115] After the EPA's failed attempt to establish an EPR-like system under the proposed National Electronics Product Stewardship Initiative, states have stepped up to fill the void.[116] The Initiative would have created a financing system for e-waste collection and recycling but the EPA could not reach an agreement with electronic producers.[117] Industry has continually fought back against mandatory EPR schemes. As states enact laws requiring EPR for a certain product, manufacturers will announce a voluntary EPR program or advance "model legislation" which lacks strong accountability but dissuades other states from passing such laws.[118] For example, in

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[112] Jennifer Nash and Christopher Bosso, *Extended Producer Responsibility in the United States*, J. of INDUS. ECOLOGY, 178 (2013).
[113] Pub. Resources § 42451(b)(4).
[114] Pub. Resources § 42451(b)(2, 6).
[115] Nash, *supra* note 114, at 175.
[116] *Id.* at 180.
[117] *Id.*
[118] *Id.* at 178.

1994, the Rechargeable Battery Recycling Corporation (RBRC) announced a nationwide system of collection sites for consumers free of charge out of fears of increased state regulation.[119] This action dissuaded states from enacting more laws and the decreased legislative pressure led to decreased efficacy of RBRC's program. Industry opposition of state-enacted EPR further exemplifies the need for federal regulation. Though the automotive industry may initially oppose any form of regulation, a federal standard will become more appealing as more states adopt EPR policies as it will offer uniformity, like in the CAA.

c. California and Lithium Ion Batteries

California has addressed the need to recycle LIBs in recent studies and action plans. In 2012, Governor Brown issued Executive Order B-16-12, which directed the state government to assist in accelerating the market for zero-emission vehicles (ZEVs) to reach a target of 1.5 million EVs in the state by 2025.[120] In 2013, Senate Bill 1275 established the goal of placing at least 1 million ZEVs, including battery EVs, in service by 2023.[121] To coordinate efforts to meet this goal, the Office of the Governor publishes EV action plans. The 2016 EV action plan stated as one of its goals to: "support new market opportunities for battery recycling and develop a commercialized pathway for second life applications of PEV [plug-in EV] batteries, including creating an ongoing stakeholder dialogue for feedback and recommendations."[122] This action item is assigned to the California Energy Commission (CEC) as head agency and the CPUC as supporting agency with a timeframe for completion of 2017.

In 2016, the CEC published a study *Direct Recycling Technology for Plug-In Electric Vehicle Lithium-Ion Battery Packs*, which evaluated current recycling processes and the

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[119] *Id.*
[120] GOVERNOR'S INTERAGENCY WORKING GROUP ON ZERO-EMISSION VEHICLES, OFF. OF GOVERNOR EDMUND G. BROWN JR., *2016 ZEV Action Plan*, 4 (2016), https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf.
[121] S.B. 1275, Reg. Sess. § 2 (Cal. 2013).
[122] GOVERNOR'S INTERAGENCY WORKING GROUP ON ZERO-EMISSION VEHICLES, *supra* note 122, at 34.

infrastructure needed to initiate LIB recycling. The study concluded that funding for this effort is critical at this time and that there is great opportunity for leadership in determining how batteries are recycled in the future.[123] Direct recycling was found to be the most cost-effective and environmentally-friendly method to reclaim materials for reuse in making new cells.[124] California can benefit economically and establish itself as a leader in the LIB recycling industry by creating a direct recycling technology program. The CEC further acknowledged LIB recycling in its *Integrated Energy Policy Report* (IEPR), released on October 16, 2017. An updated IEPR is released every two years and acts as a policy planning tool through analysis of trends and issues in the energy sector. The 2017 IEPR states that determining how California will address the EOL stage of battery systems warrants further consideration, particularly in the context of increasing in-state electricity storage opportunities.[125]

As stated in the CEC's study, California has the potential to be a national and global leader in LIB recycling. California is a public supporter of electrifying the transportation sector and has the potential to, once again, initiate environmental progress.

V. INTERNATIONAL COMMUNITY

In contrast with the United States, the EU regulates the collection and disposal of EV and hybrid vehicle batteries, including LIBs. Two policies lay out these regulations: the EU Battery Directive and the End of Life (ELV) Directive. These Directives provide a particularly important case study for the United States because they enact EPR on a national scale.

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[123] Hailey, *supra* note 43, at 4.
[124] *Id.* at 22.
[125] CAL. ENERGY COMM'N, 2017 DRAFT INTEGRATED ENERGY POLICY REPORT, 130 (2017), http://docketpublic.energy.ca.gov/PublicDocuments/17-IEPR-01/TN221520_20171016T153945_Draft_2017_Integrated_Energy_Policy_Report.pdf.

The EU Battery Directive introduces policies that regulate the manufacturing and disposal of a variety of batteries, including automotive and industrial batteries. Lead acid batteries fall under the automotive category whereas LIBs and any batteries used in EVs are considered industrial batteries.[126] Particularly noteworthy aspects of the EU Battery and ELV Directives are rules setting forth recycling efficiency goals and battery collection schemes, EPR, and inclusion of consumers in the recycling process.

a. Specific Rules for Electric Vehicle Batteries

The Directives set out specific rules for industrial batteries: use of mercury and cadmium is restricted, battery producers must take back waste batteries regardless of chemical composition or origin, all collected batteries must be recycled, battery disposal in landfills or by incineration is restricted, recycling processes must achieve a minimum efficiency of 65% for lead acid batteries, 75% for nickel-cadmium and 50% for all other batteries, batteries must be readily removable from appliances, appliances containing batteries must have instructions demonstrating safe removal, and batteries must be labelled with a recycle symbol and appropriate chemical symbols if they contain more than a specified amount of mercury, cadmium or lead.[127]

All EU Member States are required to establish battery collection schemes, although battery producers and third parties may manage them.[128] Batteries collected after a car has ended its useful life are governed under the ELV Directive but all other battery removals, such as batteries removed for replacement during the "use phase" of the vehicle, fall under the Battery

[126] Directive 2006/66, of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC, art. 3(6), 8(3), 14, 2006 O.J. (L 266) 1, 9, 13, 16.
[127] Directive 2000/53 of the European Parliament and of the Council of 18 September 2000 on end-of-life vehicles, art. 4(2)(a), 2000 O.J. (L 269/34), 34, 37; *see also* Battery Directive art. 8(3), 12(1)(b), 14, Annex III (b), art. 11, 21(3).
[128] Battery Directive art. 8.

Directive.[129] By establishing a collaborative system between the government and private companies, the EU recognizes the role industry can play while ensuring that the government will collect batteries if or before industry begins to do so on a large-scale. The dual scheme between the Directives further ensures all batteries will be regulated, regardless of the time of removal.

b. Producer Responsibility

Producer responsibility requires battery producers and anyone who places batteries or products with batteries onto the market to take responsibility for the resulting waste. Producers who place more than one ton of batteries on the market each year are required to pay for the collection, treatment, recycling and disposal of batteries in proportion to their market share.[130] Producers may coordinate with private companies to collect, treat, recycle and dispose of their batteries.[131] If producers work with private companies, they must still register with their local environmental agency.[132] Smaller producers who place less than one ton of batteries on the market per year are not charged for recycling or disposal but also must register with their local environmental agency.[133]

c. Inclusion of Consumers

Under the Directives, consumers play a role in the recycling process. The EU Battery Directive requires Member States to inform consumers of the chemicals and substances used in batteries and provide information on the meaning of battery labels and symbols.[134] Consumers

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[129] EUR. COMM'N DOCTORATE GEN. ENV'T, FREQUENTLY ASKED QUESTIONS ON DIRECTIVE 2006/66/EU ON BATTERIES AND ACCUMULATORS AND WASTE BATTERIES AND ACCUMULATORS 1, 24 (2014), http://ec.europa.eu/environment/waste/batteries/pdf/faq.pdf.
[130] Environmental Protection, The Waste Batteries and Accumulators Regulations 2009 No. 890 of 14 April 2009 1, 9, 12, http://ec.europa.eu/environment/waste/batteries/pdf/faq.pdf.
[131] *Id.* at 12.
[132] *Id.* at 60-61.
[133] *Id.* at 14.
[134] EU Battery Directive, art. 20.

must be notified of treatment facilities, how they can reuse, recycle, or recover ELV components, and what progress is being made in achieving recyclability of vehicle batteries.[135] Under the ELV Directive, economic operators are required to provide information on how their vehicles and component parts are designed to be recovered and recycled.[136] Producers also must provide registration bodies with information on the types of batteries they place on the market.[137]

d. Integrating European Union Policies in the United States

The United States and EU generally diverge on policies for emerging technologies, with the EU taking a more precautionary approach involving consumers and the United States a post-hoc regulatory approach. One reason for this divergence is that the EU has a relatively decentralized system compared to the United States' federal system.[138] This results in a more politically insulated process in the United States that tends to be slower in enacting policies and less responsive to consumer sentiments.[139]

The emerging technology of genetically modified organisms (GMOs) exemplifies this divergence and provides a comparison to LIB regulation. In both GMO and LIB development, lack of federal regulations in the United States led to increased adoption of the technologies in the market. As a result, the GMO industry lobbied strongly against stringent government regulations and it is likely the LIB industry will do the same. In contrast, the EU adopted a restrictive regulatory system early in GMO and LIB technology development, allowing industry to adapt to regulations. The EU's restrictions on GMOs directed and ultimately decreased development as investments moved to other markets and consumer support decreased.[140] The EU

[135] ELV Directive art. 9(2).
[136] *Id.*
[137] EU Battery Directive, Annex IV, 2 (iii).
[138] Mark A. Pollack and Gregory C. Shaffer, WHEN COOPERATION FAILS 72 (2009).
[139] *Id.*
[140] *Id.* at 79.

Battery and ELV Directives also direct LIB development by phasing out certain materials and increasing recycling. Based on the United States' political framework and general support of industry innovation, it unlikely that the EU's LIB recycling framework will be adopted in its entirety in the United States. However, the Directives offer regulatory approaches that could be integrated directly or indirectly via market forces into United States policies.

The United States should consider adopting the EU's framework of consumer and private sector inclusion. The EU's coordinated approach between government and private parties in battery collection schemes could be effective in the United States since industry is already moving forward in the government's absence and establishing recycling programs. In addition, adopting a policy that prioritizes consumer awareness on how to recycle car batteries and the government's progress in the area would create a more transparent system. Transparency is essential in generating market acceptance and public trust of emerging technologies. GMOs have suffered from low public trust as a result of lack of transparency by industry and the government. In contrast, the nanotechnology industry recognized the importance in gaining public trust through public engagement and tried to integrate this principle early on in its development.[141] This has garnered greater public acceptance of the benefits of nanotechnology than GMO foods, without damaging nanotechnology development and policy.[142] Introducing consumers to the process may increase public support for EVs by alleviating concerns of battery waste.

The Directives may also influence United States policy indirectly through market forces. This occurred with chemical regulation after the EU passed the Registration, Evaluation, and Authorization of Chemicals (REACH) in 2006. Chemical companies in the United States with

[141] Albert C. Lin, PROMETHEUS REIMAGINED: TECHNOLOGY, ENVIRONMENT, AND LAW IN THE TWENTY-FIRST CENTURY 96 (2013).
[142] *Id.*

substantial business in Europe began applying REACH requirements for toxicity testing and information disclosure into their internal practices.[143] Once companies were spending money to comply with these requirements, they had an incentive to support similar regulations in the United States to level the playing field with domestic competitors.[144]

REACH also generated information that could be used by the United States and international community.[145] The EU Directives could have a similar effect in battery recycling by generating information regarding collection rates, recycling processes, and how the government and private industry work together in such a regulatory scheme. If American battery producers with business in the EU start taking producer responsibility, support for federal EPR regulations requiring all American producers to do the same will likely follow.

VI. INDUSTRY

In the absence of federal regulation, both recycling and automotive industries have begun responding to the issue of LIB waste. These actions include establishing start-up companies that recycle batteries from car manufacturers and writing safety standards.

a. How Lithium Ion Batteries are Processed Today

There are a handful of private companies offering hybrid and EV battery recycling including American companies Retriev Technologies (California) and Battery Solutions (Michigan), and international companies Umicore (Belgium), American Manganese Inc. (Canada), and Li-Cycle (Canada). Vinayak Yannam, manager of business research and advisory at Aranca, a global research and analytics company, explains that there are only a handful of specialist recyclers on the market because it is not economically viable with respect to the small

[143] Doremus, *supra* note 6, at 28.
[144] *Id.*
[145] *Id.*

base load of EOL batteries.[146] Many EV batteries are simply being stored away until there is a sufficient amount to make the process economical.[147] Some car manufacturers, such as Honda, Tesla, GM and Nissan have developed recycling capabilities for their specific variations of batteries.[148] In the future, Yannam says that the manufacturers will need to work together to develop standardized batteries to allow large-scale recycling.[149] However, automakers are very protective when it comes to their specific battery formulations which will complicate a collaborative scheme.

b. Case Study: Tesla

Tesla provides an interesting case study because it is developing a robust recycling process with private recycling companies to recycle their batteries. In North America, Tesla partners with Kinsbursky Brothers, a major stakeholder in Retriev Electronics, and in Europe, Umicore.[150] Before sending the battery packs to these recycling companies, Tesla reuses about 10% of them, including the battery case and some of the electronic components.[151]

Umicore separates the batteries into products and byproducts through a process of smelting and leaching. The products, an alloy refined into cobalt, nickel and other metals, can be used to make lithium cobalt oxide which is a valuable product for battery manufacturers.[152] Creating products and byproducts results in Umicore saving at least 70% on carbon dioxide

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[146] Maura Keller, Recyclability of Electric Vehicle Batteries Scrutinized, AM. RECYCLER NEWS (Oct. 2017), http://americanrecycler.com/8568759/index.php/news/category-news-2/2643-recyclability-of-electric-vehicle-batteries-scrutinized
[147] *Id.*
[148] *Id.*
[149] *Id.*
[150] Kurt Kelty, *Tesla's Closed Loop Battery Recycling Program*, TESLA (Jan. 26, 2011), https://www.tesla.com/blog/teslas-closed-loop-battery-recycling-program?redirect=no
[151] *Id.*
[152] Henry Sanderson, Rise of Electric Cars Poses Battery Recycling Challenge, FIN. TIMES (Sept. 3, 2017), https://www.ft.com/content/c489382e-6b06-11e7-bfeb-33fe0c5b7eaa

emissions compared to a mechanical separation process.[153] Tesla reports that working with Umicore has allowed them to fully recycle their Roadster battery packs profitably, without requiring special financial incentives to promote recycling.[154] Tesla aspires to recycle batteries back into their raw materials so they can be reused in battery cells and parts, achieving a closed loop recycling process.[155]

It is important to note that Umicore does not directly recover lithium; instead, lithium becomes part of a mixed byproduct.[156] While Umicore could recover lithium from the byproduct, the extra process comes with a cost which means that not all batteries taken to its recycling facilities result in recovered lithium. Recovering lithium is necessary to create a closed loop LIB recycling process.

c. Safety Standards

In addition to recycling processes, industry is also establishing safety standards. The federal government has not yet adopted a test safety manual for uniform testing of LIBs so individual automakers are writing their own internal standards.[157] The problem is that there are significant costs, experimental challenges, and safety hazards in testing LIBs.[158] Damaged LIBs in particular carry risks such as thermal runaway, electric shock, and hazardous substance emissions to the workers who handle them.[159] During the actual recycling process, LIBs can explode through radical oxidation.[160] This occurs when lithium metal produced from the battery

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[153] *Id.*
[154] Kelty, *supra* note 154.
[155] *Id.*
[156] Joey Gardiner, The Rise of Electric Cars Could Leave Us With a Big Battery Waste Problem, THE GUARDIAN (Aug. 10, 2017 4:15), https://www.theguardian.com/sustainable-business/2017/aug/10/electric-cars-big-battery-waste-problem-lithium-recycling.
[157] Lebov, *supra* note 13, at 88-89.
[158] *Id.*
[159] https://elibama.files.wordpress.com/2014/10/v-d-batteries-recycling1.pdf.
[160] Ordonez, *supra* note 15, at 198.

overcharges and sustains a mechanical shock on exposure to the air.[161] The manual dismantling of cathode materials also exposes workers to toxic volatile organic compounds (VOCs).[162] Testing and establishing safety standards is an area where the government has the capability to provide guidance, whether it be through national safety standards or by providing financial assistance to private companies to test LIBs.

VII. RECOMMENDATIONS

Timely regulation is required to address EOL LIBs. Since the metals contained in LIBs are valuable and demand for battery packs is projected to increase, the two most logical solutions are to find a second use for the batteries in the short-term and ultimately recycle them in a closed loop process.

a. Short-Term Solution: Second Life Uses

EV batteries are replaced with a new battery pack once their efficiency decreases to 80%, leaving a significant amount of functional energy life.[163] Once battery efficiency decreases to this level, they are no longer sufficient for automotive use; car manufacturers report that the amount of decreased efficiency that accompanies a 20% reduction would be unacceptable to customers.[164] In response, manufacturers, including GM, Nissan, and Toyota, offer long-term warranties for their battery packs.[165]

A second life use system would be economically and environmentally advantageous in the short-term before there is a sufficient number of LIBs ready to be recycled. These benefits include longer lifetime use of valuable chemicals, distributing costs among two sectors, reducing

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[161] *Id.*
[162] Jiefeng Xiao, *Recycling Metals from Lithium Ion Battery by Mechanical Separation and Vacuum Metallurgy*, 338 J. OF HAZARDOUS MATERIALS 124, 125 (2017).
[163] Narula, *supra* note 4, at xvii.
[164] *Id.*
[165] *Id.*

waste, and decreasing the amount of energy required to create new batteries.[166] A report created for the CEC identified the following potential second life uses for LIBs: residential and commercial electric power management, power grid stabilization, and renewable energy system firming by providing storage.[167] Nissan is exploring this third use, stabilizing renewable energy systems, by partnering with the power management firm Eaton to use their EOL LIBs as home energy storage.[168] Francisco Carranza, Director of Energy Services at Nissan, stated Nissan's decision to reuse rather than recycle LIBs was largely an economic decision: "Cost of recycling is the barrier…it has to be lower than the value of the recovered materials for this to work."[169] Carranza explained that the value of the raw materials that can be reclaimed is currently a third of the price of fully recycling a battery.[170]

LIBs can also be used to power parts of the LIB recycling process. Useful amounts of energy can be extracted from discharging batteries to heat the leaching vessel during the recycling process.[171] Finding second life uses for LIBs will result in reduced prices for second users and environmental benefits but offers limited economic benefits to the EV industry. Second use is only estimated to discount battery prices by a maximum of 12%.[172]

b. Long-Term Solution: Closed Loop Recycling

Ultimately, LIBs need to be recycled in a closed loop process. The federal government can play a key role in establishing a sustainable program by providing support during initiation, when recycling has not yet proven profitable on a large-scale as only a small number of LIBs are

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166 *Id.*
167 Andris Abele et al., CAL. ENERGY COMM'N, 2020 STRATEGIC ANALYSIS OF ENERGY STORAGE IN CALIFORNIA, 22 (2011).
168 Gardiner, *supra* note 159.
169 *Id.*
170 *Id.*
171 Sonoc, *supra* note 2, at 756.
172 Jeremy Neubauer and Ahmad Pesaran, U.S. DEP'T OF ENERGY NATIONAL RENEWABLE ENERGY LABORATORY, NREL/CCSE PEV BATTERY SECOND USE PROJECT 4, https://www.nrel.gov/transportation/assets/pdfs/52626.pdf.

being recycled and battery compositions differ. First, the government should establish a program to research more efficient direct recycling processes that can remove multiple metals from a single battery pack. This type of research program was presented in the proposed Rare Earth Recycling Research Initiative.

Next, the federal government should pass legislation modeled after the lead acid battery program allowing alternative, flexible standards and prohibiting export under RCRA. This will encourage proper disposal which is vital considering there is a current disincentive to collect batteries.

Finally, looking to the EU's system of producer responsibility and California's new lead acid battery financing scheme, the federal government should establish EPR to ensure battery producers and manufacturers are responsible for all LIBs placed onto the market. A federal EPR system is the most effective way to regulate the nationwide automotive industry. EPR may include a similar battery fee charged to consumers as in California's Lead Acid Battery Act or assign full responsibility to battery producers, as established in the EU Directives.

While second life battery use provides one route for disposal of LIBs, a closed loop recycling process will be imperative long-term to meet an increasing demand for EVs. This is an issue the government cannot and should not put on the back burner. As stated in the CEC report, there is great economic advantage and leadership to be gained in discovering the technology that will allow streamlined and cost-effective LIB material recovery. Now is the time to establish regulations for this emerging technology.