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

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I. INTRODUCTION

The number of electric vehicles (EVs) on the road is rising and projected to 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] Recycling these batteries is imperative to protect human health, the environment, and the natural supply of lithium.

The preferred battery choice for EVs is lithium ion batteries (LIBs). Presently, only three percent of LIBs are recycled, and lithium recovery is negligible.[2] At this minimal rate, lithium demand will outstrip supply by 2023.[3] While potential fire hazards of lithium batteries in transportation are regulated by the U.S. Department of Transportation (DOT), there are no regulations concerning 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 on the road today 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 the number of LIBs discarded to roughly 295,000.[5] Comprehensive federal legislation and safety laws are greatly needed now to prepare for this wave of waste.

States can be an important catalyst for federal action. The history of the Clean Air Act (CAA) exemplifies that automobiles are a national market and that the industry benefits from comprehensive federal regulation. California 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

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1 S. Rohr et al., *Quantifying Uncertainties in Reusing Lithium-Ion Batteries from Electric Vehicles*, 8 PROCEDIA MANUFACTURING 603 (2017).

2 Alexandru Sonoc. et al., *Opportunities to Improve Recycling of Automotive Lithium Ion Batteries*, 29 PROCEDIA CIRP 752 (2015).

3 *Id.*

4 CHAITANYA K. NARULA ET AL., OAK RIDGE NAT'L LAB., FINAL REPORT: ECONOMIC ANALYSIS OF DEPLOYING USED BATTERIES IN POWER SYSTEMS 2-3 (June 2011).

5 *Id.*

6 HOLLY DOREMUS ET AL., ENVIRONMENTAL POLICY LAW: PROBLEMS, CASES, AND

the Motor Vehicle Air Pollution Control Act in 1965, laying the groundwork for the 1970 Amendments to the CAA.[7] The 1970 Amendments set nationwide standards for air pollution emissions from mobile sources and preempt 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]

Auto manufacturers generally supported federal regulation because of growing concerns 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. The CAA illustrates that federal regulation could offer uniformity and, consequently, be preferable to industry.

Further, the federal government is better suited than states to regulate LIB recycling. The Commerce Clause of the Constitution provides Congress with authority to regulate 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.

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).This paper discusses the feasibility of implementing these recommendations by evaluating federal and state government actions, as well as legislation enacted in the EU and responses by the automobile industry. Both short and long-term solutions are proposed to integrate LIB recycling in the United States.

EPR shifts the cost of recycling from governments in charge of waste management to producers by having battery producers internalize recycling costs. So far, EPR has been enacted only on the state level and has not been

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READINGS 697 (Robert C. Clark et al. eds., 6th ed. 2012).

7 *Id.* at 697-698.

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).

adopted into federal policies.[13] Since automobiles represent a nationwide market, federal EPR regulations should be adopted for LIBs. The European Union (EU) has enacted an EPR scheme for LIBs and other types of automotive vehicle batteries. As such, the EU provides a useful case study for the United States.

While standardizing LIB battery compositions would allow streamlined recycling, standardization has the potential to stifle technological innovation and may be politically infeasible. Automobile manufacturers are secretive when it comes to their battery compositions and would likely 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.

II. Background on Lithium Ion Batteries and the Need to Recycle

In 1991, LIBs were first commercialized by the electronics company Sony for mobile devices.[14] 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.[15]

LIBs are the preferred battery choice for electronic devices and EVs because they have characteristics that are conducive to rechargeable and portable systems.[16] 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.[17] In the past, hybrid and EVs relied on nickel metal hydride (NiMH) batteries, but LIBs are expected to dominate the market moving forward.[18] The International Energy Agency projects that the annual production of LIBs for EV use will rise to 100 million in 2050.[19] This growing market will

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13 Jennifer Nash & Christopher Bosso, *Extended Producer Responsibility in the United States*, 17 J. Indus. Ecology 175, 175 (2013).

14 Harrison Lebov, Note, *A Darker Shade of Green: Hazards Associated with Lithium Ion Batteries*, 17 J. High Tech. L. 78, 81 (2016).

15 Lew Fulton, et al., U.C. Davis Inst. of Transp. Stud., Three Revolutions in Urban Transportation 1, 8 (2017), https://www.itdp.org/wp-content/uploads/2017/04/UCD-ITDP-3R-Report-FINAL.pdf.

16 Sonoc, *supra* note 2, at 752.

17 J. Ordonez et al., *Processes and Technologies for the Recycling and Recovery of Spent Lithium-Ion Batteries*, 60 Renewable and Sustainable Energy Reviews 195, 196 (2016).

18 Guillaume Majeau-Bettez, et al., *Life Cycle Environmental Assessment of Lithium-Ion and Nickel Metal*
Hydride Batteries for Plug-In Hybrid and Battery Electric Vehicles, Env't Science and Tech., 2011, at 4548.

19 Sonoc, *supra* note 2, at 752.

greatly increase demand on natural lithium supplies and create a significant amount of waste that needs to be reused and repurposed rather than sent to landfills.

A. *Global Lithium Supply and Scarcity*

Lithium is a relatively plentiful naturally occurring material, but supplies are concentrated in select regions of the world. South America retains most of the global lithium supply. Chile holds approximately three-quarters of the world's currently accessible lithium reserves, while the next largest reserves are in Argentina and Australia, accounting for 14%.[20] 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 promised to protect.[21] In addition to being limited to a few regions of the world, mining and extracting lithium is costly and environmentally harmful.[22] Smelting, a process used 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) .[23]

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*

1. Environmental Hazards

The human health, toxicity, and environmental impacts of a LIB depend on its design, particularly in the choice of active material for the cathode, as the battery's design affects the resulting extraction of metal, processing of materials, and energy use. A study conducted by the EPA found that battery chemistries with more aluminum showed a higher potential for ozone depletion compared to

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20 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).

21 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).

22 Linda Gaines, *The Future of Automotive Lithium-Ion Battery Recycling: Charting a Sustainable Course*, SUSTAINABLE MATERIALS AND TECH., Nov. 2014, at 1.

23 *Id.*

nickel cobalt manganese lithium ion (Li-NCM) batteries.[24] However, Li-NCM batteries are not necessarily more environmentally friendly than other designs of LIBs; Li-NCM batteries require twice as much primary energy and contain rare metals that have significant non-cancer and cancer toxicity potential.[25]

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.[26] Potentially toxic materials in LIBs are copper, nickel, lead and organic chemicals, such as toxic and flammable electrolytes.[27] Accordingly, LIBs are classified as Class 9 miscellaneous hazardous materials by U.S. DOT and regulated during transport under Title 49 of the Code of Federal Regulation (CFR).[28] "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."[29] Overheating LIBs poses a fire risk, particularly in aviation transportation. Regulations subject LIBs in transit to complex inspection, testing, packaging, labeling, recordkeeping, and notification requirements.[30]

2. Health Hazards

Lithium additionally poses health risks to humans and animals, as it can be absorbed and accumulated in edible plants and thus enter the food chain.[31] Health risks include genetic toxicity, reproductive toxicity and gastrointestinal toxicity.[32] Genetic toxicity from 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.[33] Lithium exposure can also affect human reproduction, resulting in accelerated incidence

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24 U.S. ENVTL. PROTECTION AGENCY, *Application of Life-Cycle Assessment to Nanoscale Technology: Lithium-ion Batteries for Electric Vehicles* 1, 102 (2013).

25 *Id*.

26 Ordonez, *supra* note 17, at 195.

27 Daniel Hsing Po Kang et al., *Potential Environmental and Human Health Impacts of Rechargeable Lithium Batteries in Electronic Waste*, ENVTL. SCI. & TECH., 5495, 5495-96 (2013).

28 Gaines, *supra* note 22, at 1.

29 Lebov, *supra* note 14, at 87.

30 Jonathan Todd et al., *Lithium Batteries in Flight: Risks and Regulations*, LAW 360, (Dec. 20, 2016, 5:09 PM), https://www.law360.com/articles/875029/lithium-batteries-in-flight-risks-and-regulations.

31 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/ (last visited Oct. 28, 2018).

32 *Id.*

33 *Id.*

of Ebstein's anomaly in babies born from mothers who receive lithium therapy, risk of fetal cardiovascular malformation, and reversible impotency in men.[34] Chronic lithium exposure and therapy can also cause gastrointestinal problems including vomiting and diarrhea.[35]

3. Legal Framework to Address Hazards

The Resource Conservation and Recovery Act (RCRA) regulates the generation, transportation, treatment, storage and disposal of hazardous solid wastes.[36] 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.[37]

A hazardous waste is subject to RCRA if it is specifically listed by the EPA or exhibits characteristics of ignitability, corrosivity, reactivity, or toxicity under prescribed testing conditions.[38] 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. [39] TCLP is the process outlined in RCRA regulations to determine whether a material is hazardous because of its toxicity.[40] All batteries tested were found to be hazardous under California regulations because they exhibited excessive levels of cobalt, copper, and, in some instances, nickel.[41] Because some LIB components are difficult to break down, they may contaminate the soil and water if disposed of in municipal waste landfills.[42] Under simulated landfill conditions, copper, cobalt, nickel and lead leached concentrations exceeding regulatory limits.[43] Additionally, incinerating LIBs releases toxic gases that

34 *Id.*
35 *Id.*
36 Doremus, *supra* note 6, at 478.
37 42 U.S.C. § 6903(5)(A)-(B), (2006).
38 Doremus, *supra* note 6, at 478.
39 Kang, *supra* note 27, at 5499; *see also* 40 C.F.R. §261.24 (a).
40 Kang, *supra* note 27, at 5496.
41 *Id.*
42 Ordonez, *supra* note 17, at 196.
43 Kang, *supra* note 27, at 5502.

contaminate the air.[44]

Under RCRA, a waste generator is responsible for determining whether its waste is a characteristic hazardous material.[45] Since LIBs are not a listed hazardous waste, and the studies discussed above tested portable electronic batteries rather than large format vehicle LIBs, generators need to test their LIBs to determine if RCRA applies. Whether a manufacturer's LIBs are subject to RCRA is a key issue, as many detailed, current regulations apply to the handling, treatment, storage and disposal of hazardous waste.[46]

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. These characteristics create two problems. The first is that current recycling processes recover far less lithium than automotive LIB manufacturers need.[47] Since recycling processes do not recover an adequate amount of materials and lithium has relatively low value, the cost of recycling currently exceeds its benefit. 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.[48] A second challenge stems from LIBs being an emerging technology. Chemical compositions of the active materials used in LIBs, particularly in the cathode, vary by manufacturer.[49] 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.[50] Different battery compositions require different recycling processes and hinder the adoption of a uniform system.

At present, there are a variety of recycling processes under consideration for large-scale LIB resource recovery: pyrometallurgical (smelting), cryogenically cooling, hydrometallurgical, and direct recycling. The smelting process uses high temperatures to burn organic materials, including the electrolyte and carbon anode, as fuels or reductants and sends the recovered valuable materials for refining.[51] The remaining materials, including lithium, are contained in the slag

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44 Ordonez, *supra* note 17, at 196.

45 40 C.F.R. § 262.11(c) (2017).

46 *See generally* 40 C.F.R. §§ 260-267.

47 Sonoc, *supra* note 2, at 756.

48 Phillip Hailey & Keith Kepler, DIRECT RECYCLING TECHNOLOGY FOR PLUG-IN ELECTRIC VEHICLES LITHIUM ION BATTERY PACKS, 3 (2015), http://www.energy.ca.gov/2016publications/CEC-500-2016-016/CEC-500-2016-016.pdf.

49 Gaines, *supra* note 22, at 5.

50 *Id.*

51 U.S. DEP'T OF ENERGY, *Recycling Batteries*, ALTERNATIVE FUELS DATA CTR.: BATTERIES FOR HYBRID AND PLUG-IN ELECTRIC VEHICLES, https://www.afdc.energy.gov/vehicles/electric_batteries.html (last visited Oct. 14, 2018).

which can be used as an additive in concrete.[52] In contrast to smelting, direct recovery processes recover battery-grade materials by separating active materials and metals through a combination of physical and chemical processes.[53] Direct recovery is a low-temperature process that requires minimal energy use.[54]

A LIB's specific design 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.[55] The 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 United States 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 Retriev (previously known as Toxco) to build America's first recycling facility for vehicle LIBs.[56] The DOE expended these funds to promote sustainable hybrid and EV batteries. The recycling facility, located in Lancaster, Ohio, is an anticipated future site for advanced large-format LIB recycling. Retriev's Vice President of the 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."[57]

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

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52 *Id.*

53 *Id.*

54 *Id.*

55 Gaines, *supra* note 22, at 6.

56 Eichner, *supra* note 20, at 275.

57 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.

exposing employees to lead and cadmium in amounts that exceeded the legal permissible exposure limit.[58] This type of exposure can damage the central nervous system, reproductive system and cause other health problems for workers.[59] Many of the violations have not been addressed by Retriev since OSHA's 2012 report, which identified and cited the company for the same hazards.[60] 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 end of life (EOL) battery stage. In 1976, Congress passed the Electric and Hybrid Vehicle Research, Development, and Demonstration Act.[61] This Act acknowledged the need to reduce the Nation's dependence on foreign oil and listed as its purposes to advance research and demonstrate the economic and technological practicability of EVs.[62] However, the Act did not discuss the EOL stage, nor has it been amended to address battery waste. Proposed legislation specifically concerning batteries and electronics provides insight for how the federal government can address LIB waste moving forward.

In 2016, the Lithium Battery Safety Act was introduced to Senate but not reported out of committee.[63] 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 more stringent than international standards.[64] It would have also created a LIB safety working group to promote and coordinate efforts related to the safe manufacture, use, and transport of LIBs.[65] Unlike recycling, LIB transportation is federally regulated; the DOT regulates the shipment, classification, and packaging of live or discharged LIBs.[66] Though the Safety Act focused on transportation and ultimately did not pass, it is promising that Congress previously recognized the need to regulate LIBs for environmental impacts and safety hazards.

The Responsible Electronics Recycling Act, introduced in the House of

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58 Dan Gearino, *Lancaster Battery Recyclers Facing OSHA Fines*, THE COLUMBUS DISPATCH (Aug. 28, 2015) http://www.dispatch.com/content/stories/local/2015/08/27/battery-recycler-OSHA-violations.html.

59 *See* 57 FED. REG. 42102 § 5 (Sept. 14, 1992); *see also Health Effects*, U.S. DEP'T OF LAB., https://www.osha.gov/SLTC/lead/healtheffects.html (last visited Nov. 1, 2017).

60 Gearino, *supra* note 58.

61 15 U.S.C. § 2501 (1976).

62 *Id.*

63 S. 2528, 114th Cong. (2016).

64 *Id.*

65 *Id.*

66 49 C.F.R. § 173.185 (2017).

Representatives in 2011 and 2013—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, projectors, audio equipment, portable gaming systems, computers, and telephones. Such restrictions incentivize domestic development of recycling methods. Motor vehicle parts, however, were specifically exempted.

Additionally, the Act would have directed the Secretary of Energy to establish a Rare Earth 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.[67] The bill listed seventeen chemical elements and enabled the Secretary to identify other elements found to be rare or in critical supply.[68] 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 was the first life cycle analysis to use data from the LIB industry in identifying what materials and processes pose the greatest risk to public health and the environment.[69] While not focused on the EOL stage, the study recognized the importance of curtailing the extraction of raw materials to preserve resources and reduce environmental impacts.[70] The findings demonstrate the upper-end potential effect of recycling on lithium demand (summarized in chart below).[71]

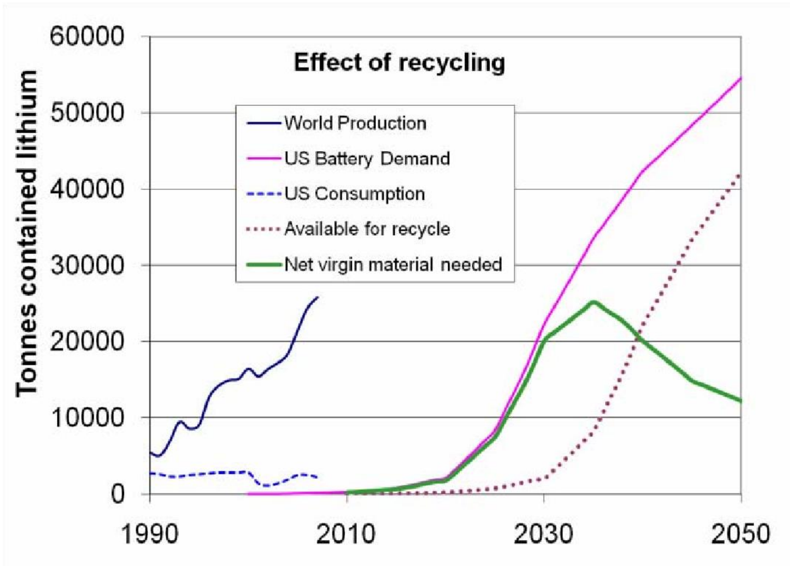
67 H.R. 2284, 112th Cong. (2011); H.R. 2791 113th Cong. (2013).

68 *Id.*

69 U.S. ENVTL. PROTECTION AGENCY, *supra* note 24, at 1.

70 *See id.* at 11.

71 *Id.* at 56.



The EPA study further 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.[72] The study recommended increasing battery lifetimes and to reduce cobalt and nickel use because of their relative toxicity.[73] With respect to recycling processes, low-temperature recycling technologies were found to be the most beneficial since they increase recovery, require less energy, and result in less material transformation.[74]

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.[75] Factors that contribute to the program's success include prohibitions on the disposal of batteries, profitability, a simple recycling process, and uniformity among almost all manufacturers in use of raw materials: lead, lead oxide and sulfuric acid.[76] 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.

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72 *Id.*

73 *Id.* at 106.

74 *Id.* at 102.

75 Sonoc, *supra* note 2, at 756.

76 Gaines, *supra* note 22, at 4.

1. Lead Acid Batteries: Laws and Regulations

The laws and regulations governing lead acid battery recycling enable 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 prohibits export, unless a generator complies with a specific set of regulatory requirements and provides two alternative management standards which exempt battery recyclers from RCRA regulations: 40 C.F.R. 266 Subpart G, and the Universal Waste Regulations in 40 C.F.R. 273.[77]

Under 40 C.F.R. 266, reclaimed lead acid batteries are exempted from certain RCRA regulations. This scheme is organized 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.[78] Lead acid battery reclaimers may alternatively choose to handle their batteries under the Universal Waste Regulations.[79]

After the passage of the Mercury-Containing and Rechargeable Battery Management Act, all fifty states had to adhere to the Universal Waste Regulations, which standardized a variety of state regulations on collecting and recycling batteries into a national program.[80] 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.[81] Generators storing batteries that will be reclaimed by regeneration—by replacing the electrolyte—are exempt from most 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 C.F.R. part 268.[82] Each battery must be specifically labeled with the words "Universal Waste—Battery", "Waste Battery", or "Used Battery" and employees must be trained in how to properly handle lead-acid batteries in the event of fire, explosions, or releases.[83]

Lead acid batteries exports are prohibited under RCRA unless the exporter has submitted a notice to the EPA requesting approval, demonstrates written

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77 James Griffin, *RCRA Options for Recycling Lead-Acid Batteries*, LION TECHNOLOGIES (Sept. 25, 2012), https://www.lion.com/lion-news/september-2012/rcra-options-for-recycling-waste-lead-acid-batteri.

78 *Id.*; *see also* 40 C.F.R. 266.80.

79 Griffin, *supra* note 77.

80 *The 1996 Battery Act: The Fulfillment of a Dream*, CALL 2 RECYCLE, https://www.call2recycle.org/1996-battery-act/ (last visited Oct. 5, 2018).

81 Griffin, *supra* note 77.

82 *Id.*

83 *Id.*

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.[84] 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.[85] These regulations help prevent exporting battery waste to disadvantaged countries for treatment in illegal or hazardous ways.

2. Lead Acid Battery Recycling: Successes and Shortcomings

Recycling lead acid batteries can be very profitable. For example, RSR Technologies and its parent company ECO-BAT, who recycle lead acid batteries, generate revenue exceeding $1 billion per year globally.[86] Recycled lead, taken to its elemental form and purified, creates a high-quality and profitable product.[87] Given 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.[88]

Recycling processes for lead acid batteries are evolving to become more environmentally friendly. In July 2016, Aqua Metals, a startup company based in Alameda, California, opened a battery recycling facility in Nevada which uses a new electrochemical process to recycle lead acid batteries from cars.[89] 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 one-fifth of the amount of greenhouse gas emissions and less than 1% of sulfur dioxide.[90] This is a particularly important development following the closure of Exide Technologies, one of two smelters on the West Coast, in Los Angeles County.

Exide Technologies permanently closed in 2015 after releasing arsenic and lead at dangerously high levels into the air.[91] Exide negotiated with the U.S. Attorney's Office to avoid criminal prosecution. In return, Exide acknowledged its criminal conduct, including illegal storage and transportation of hazardous

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84 Letter from Mathy Stanislaus, Admin. Assistant, U.S. Envtl. Protection Agency, to Robert Finn, CEO and President, RSR Corp (Sept. 12, 2011) (indexed by RCRA Online).

85 *Id.*

86 Hailey & Kepler, *supra* note 48, at 5.

87 Gaines, *supra* note 22, at 4.

88 Hailey & Kepler, *supra* note 48, at 5.

89 David R. Baker, *In the Shadow of the Gigafactory, a New Way to Recycle Batteries*, S.F. CHRON (July 28, 2016), http://www.sfchronicle.com/business/article/In-the-shadow-of-the-Gigafactory-a-new-way-to-8529299.php.

90 *Id.*

91 *Id.*

waste, and promised to shut down, demolish, and clean its 15-acre battery recycling plant.[92] This marked 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.[93] The South Coast Air Quality Management District found Exide's arsenic emissions endangered 110,000 residents in nearby communities.[94] Exide does not represent an isolated occurrence. Lead acid battery recycling is one of the worst polluting industries worldwide[95] and, because lead is a highly toxic metal, improper treatment can have serious environmental effects. If one lead acid battery is incorrectly disposed of in a municipal solid waste (MSW) system, it can contaminate 25 tons of waste and prevent the recovery of organic resources.[96]

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

Key differences between lead acid batteries and LIBs make an identical recycling program infeasible for several reasons. In contrast to standard lead acid batteries, LIB designs are rapidly evolving. LIBs also have a wider variety of materials in each cell: a LIB pack may have 100 or more individual cells (Tesla's LIB battery packs, for example, contain around 5,000 cells) connected into modules and assembled into a battery pack with control circuits attached to each cell.[97] In comparison, lead acid batteries have a relatively small number of lead plates in a single plastic case. LIBs also sometimes contain a thermal management system.[98]

A LIB's design changes the economic return of recycling since elements have different pecuniary values once recovered. Despite being 100% recyclable, procuring recycled lithium can cost up to five times more than brine-based mined lithium.[99] While lithium can be extracted from the slag produced from LIB recycling, it is currently not profitable or competitive to do so.[100] Instead, slag is sold to non-automotive industries, including construction,

92 Tony Barboza, *Exide Closing Vernon Plant to Avoid Criminal Prosecution*, L.A. TIMES (Mar. 11, 2015), http://www.latimes.com/local/crime/la-me-0312-exide-20150312-story.html.

93 *Id.*

94 *Id.*

95 Andrew Ballantyne, et al., *Lead Acid Battery Recycling for the Twenty-First Century*, ROYAL SOCIETY OPEN SCIENCE, 2018.

96 Salman Zafar, *The Problem of Used Lead Acid Batteries*, ECOMENA (July 30, 2016), https://www.ecomena.org/managing-lead-acid-batteries/ (last visited Oct. 28, 2018).

97 Gaines, *supra* note 22, at 5.

98 *Id.*

99 *See The Lithium Battery Recycling Challenge*, WASTE MGMT. WORLD, https://waste-management-world.com/a/1-the-lithium-battery-recycling-challenge (last visited Jan. 8, 2011).

100 *Id.*

pharmaceuticals, ceramics, and glass.[101] 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 smaller quantities.[102] In contrast, lead acid batteries are 70% lead by weight and recycling batteries produces a quality product equivalent to primary mined lead.[103]

Another difference is that lead acid batteries are small in size and easily removable from under the hood of a car, whereas LIBs are larger and vary in shape and location in vehicles.[104] 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 should be recycled because of their resource value and potential environmental harm. Second, infrastructure is currently in place to collect and recycle large volumes of lead acid batteries. Third, there is a regulatory scheme in place that could translate into a LIB recycling program. Implementing flexible regulatory options and a prohibition on exports, as used for lead acid batteries, could help 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 a financing scheme similar to EPR for lead acid batteries. The Act applies to lead acid batteries weighing more than 5 kilograms and includes starting batteries and motive power batteries used in vehicles.[105] Existing California law prohibits

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101 *Id.*

102 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/.

103 *Id.*; *see also Lead Recycling*, INT'L LEAD ASS'N, https://www.ila-lead.org/lead-facts/lead-recycling (last visited Nov. 26, 2017).

104 Gaines, *supra* note 22, at 5.

105 *See* CAL. HEALTH & SAFETY CODE §§ 25215.1(e), 25215.25, 25215.35.

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 used lead acid batteries at point of transfer and establishes a "battery fee" for both the consumer and manufacturer.[106]

The new financing scheme imposes a non-refundable "California battery fee" and a refundable deposit for each lead acid battery purchased from a dealer.[107] 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.[108] Every dealer is required to collect the battery fee, currently $1 per battery but raised to $2 per battery on April 1, 2022, at time of sale and may retain 1.5% of the fee as reimbursement for any costs associated with collection.[109] 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.[110]

The BOE uses the collected money for refunds, reimbursements, and to support the "Lead Acid Battery Cleanup Fund" within the State Treasury.[111] 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.[112] The collection from manufacturers is used, in part, to reduce the manufacturer's share of liability in tort actions related to hazardous substance releases from lead acid recycling facilities.[113]

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.[114] 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.[115]

Establishing a cleanup fund, battery recyclability labeling requirements, 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

106 *Id.* § 25215.2 (a).
107 *Id.* § 25215.2 (c).
108 *Id.*
109 *Id.* §§ 25215.25 (a)(1), (3).
110 *Id.* § 25215.35.
111 *Id.* § 25215.5 (a).
112 *Id.* § 25215.5 (b).
113 *Id.* §25215.7.
114 *Id.* §25215.65.
115 *Id.* §25215.45 (b).

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. This would mitigate accidental inclusion of LIBs in secondary lead smelter input streams, which has resulted in fires and explosions.[116] Labelling could also establish a way to easily sort LIBs from lead acid batteries and 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.

B. *Extended Producer Responsibility and E-Waste*

California and seven other states have enacted EPR laws regulating rechargeable batteries.[117] California's law provides 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 government.[118] The statute provides that California's recycling program should be convenient for consumers and provides manufacturers with the flexibility to partner with other manufacturers and businesses to establish a recycling program.[119]

California provides just one example of a state enacted EPR law. Over the past twenty years, numerous states have enacted more than seventy EPR laws, forty of those passed since 2008.[120] After the EPA failed to establish an EPR system under the proposed National Electronics Product Stewardship Initiative in the early 2000s, states have stepped up to fill the void.[121] The EPA's Initiative would have created a financing system for e-waste collection and recycling; however, the EPA could not reach an agreement with electronic producers.[122] Industry has continually fought mandatory EPR schemes. As states enact laws requiring EPR for a certain product, manufacturers often announce a voluntary EPR program or advance "model legislation" which lacks strong accountability but dissuades other states from passing such laws.[123] For example, in 1994, the Rechargeable Battery Recycling Corporation (RBRC) announced a nationwide collection system for consumers free of charge out of fears of increased state

116 Gaines, *supra* note 22, at 6.
117 Jennifer Nash & Christopher Bosso, *supra* note 13, at 178.
118 CAL. PUB. RES. CODE § 42451(b).
119 *Id.* § 42451(b)(6).
120 Nash, *supra* note 117, at 175.
121 *Id.* at 180.
122 *Id.*
123 *Id.* at 178.

regulation.[124] This action dissuaded states from enacting more laws and the decreased legislative pressure led to decreased efficacy of RBRC's program.[125] Industry opposition to state-enacted EPR further exemplifies the need for federal regulation. Though the automotive industry may initially oppose regulation, a federal standard will become more appealing as more states adopt EPR policies. A federal standard would offer uniformity and may become industry's preference, as exemplified in the CAA.

C. *California and Lithium Ion Batteries*

In addition to the abovementioned legislative actions, California state actors have 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.[126] In 2013, Senate Bill 1275 established the goal of placing at least 1 million ZEVs, including battery EVs, on the road by 2023.[127] To coordinate efforts to meet this goal, the Office of the Governor publishes EV action plans. The 2016 EV action plan sought to "support new market opportunities for battery recycling and develop a commercialized pathway for second life applications of plug-in electric vehicles (PEV) batteries, including creating an ongoing stakeholder dialogue for feedback and recommendations."[128] This action item is assigned to the California Energy Commission (CEC) as head agency and the California Public Utilities Commission (CPUC) as supporting agency with a timeframe for completion of 2017.

In 2016, the CEC published a study entitled *Direct Recycling Technology for Plug-In Electric Vehicle Lithium-Ion Battery Packs*, which evaluated current recycling processes and the infrastructure needed to initiate LIB recycling. The CEC concluded that funding for recycling is critical at this time and that there is great opportunity for leadership in determining how batteries are recycled in the future.[129] Direct recycling was found to be the most cost-effective and environmentally-friendly method to reclaim materials for reuse in making new LIB cells.[130] Thus, California can benefit economically and establish itself as a

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124 *Id.*

125 *Id.*

126 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 (last visited Oct. 28, 2018).

127 S.B. 1275, Reg. Sess. § 2 (Cal. 2013).

128 GOVERNOR'S INTERAGENCY WORKING GROUP ON ZERO-EMISSION VEHICLES, *supra* note 126, at 32.

129 Hailey, *supra* note 48, at 4.

130 *Id.* at 22.

leader in the LIB recycling industry by creating a direct recycling technology program. The CEC also acknowledged LIB recycling in its *Integrated Energy Policy Report* (IEPR), released in October 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.[131]

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 large scale.

The EU Battery Directive regulates 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.[132] Batteries collected after a car has ended its useful life are governed under the ELV Directive; however, all other battery removals, such as batteries removed for replacement during the "use phase" of the vehicle, fall under the Battery Directive.[133] 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, including: restricting mercury and cadmium, requiring battery producers to take back waste

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131 *See* 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 (last visited Oct. 28, 2018).

132 Council Directive 2006/66 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.

133 Council Directive 2000/66 Eur. Comm'n Doctorate Gen. Env't, Frequently Asked Questions on Directive 2006 O.J. (L 266) 1, 24 (2014).

batteries regardless of chemical composition or origin, recycling all collected batteries, and restricting battery disposal in landfills or by incineration. In addition, 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.[134]

All EU Member States are required to establish battery collection schemes, although battery producers and third parties may manage them.[135] 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.[136] Producers may coordinate with private companies to collect, treat, recycle and dispose of their batteries.[137] If producers work with private companies, they must still register with their local environmental agency.[138] 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.[139]

C. *Consumer Inclusion*

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

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134 Directive 2000/53 of the European Parliament and of the Council of 18 Sept. 2000 on the 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).

135 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. 8.

136 *Id.* at 1, 9, 13.

137 *Id.* at 10, 13.

138 McManus, *supra note* 21, at 8-9.

139 Council Directive, *supra* note 133, at 14.

battery labels and symbols.[140] Consumers 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.[141] 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.[142] Producers also must provide registration bodies with information on the types of batteries they place on the market.[143]

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 exercising a post-hoc regulatory approach. One reason for this divergence is that the EU has a relatively decentralized political system compared to the United States' federal system.[144] 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.[145]

Genetically modified organisms (GMOs) are an example of an emerging technology in food that illustrates 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 against stringent government regulations and the LIB industry will likely do the same. In contrast to the U.S., the EU adopted a restrictive regulatory system early in GMO and LIB technology development, enabling 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.[146] The EU 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 is unlikely that the EU's LIB recycling framework will be adopted in its entirety in the United States. However, the Directives provide an example of regulatory approaches that could be integrated directly or indirectly via market forces into United States policies.

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140 EU Battery Directive, art. 20.

141 ELV Directive art. 9(2).

142 *Id.*

143 Directive 2013/56 of the European Parliament and of the Council of 20 November 2013 amending Directive 2006/66/EC of the European Parliament and of the Council on Batteries and Accumulators and Waste Batteries and Accumulators as Regards the Placing on the Market of Portable Batteries and Accumulators Containing Cadmium Intended for Use in Cordless Power Tools, and of Button Cells with Low Mercury Content, and Repealing Commission Decision 2009/603/EC Text with EEA relevance, 2013 O.J. (L 329), Annex IV, 2 (iii).

144 Mark A. Pollack & Gregory C. Shaffer, WHEN COOPERATION FAILS 72 (2009).

145 *Id.*

146 *Id.* at 79.

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. For example, GMOs in food 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 integrated this principle early on in its development.[147] This garnered greater public acceptance of the benefits of nanotechnology than GMO foods, without damaging nanotechnology development and policy.[148]

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 substantial business in Europe began applying REACH requirements for toxicity testing and information disclosure into their internal practices.[149] 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.[150]

REACH also generated information that could be used by the United States and international community in enacting their own regulations.[151] 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 are subject to producer responsibility, support for federal EPR regulations requiring all American producers to do the same may follow.

VI. INDUSTRY

In the absence of federal regulation, both recycling and automotive industries

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147 Albert C. Lin, PROMETHEUS REIMAGINED: TECHNOLOGY, ENVIRONMENT, AND LAW IN THE TWENTY-FIRST CENTURY 96 (2013).

148 *Id.*

149 Doremus, *supra* note 6, at 28.

150 *Id.*

151 *Id.*

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. Among these companies are 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 base load of EOL batteries.[152] Many EV batteries are simply being stored away until there is a sufficient amount to make the recycling process economical.[153] Some car manufacturers, such as Honda, Tesla, GM and Nissan have developed recycling capabilities for their specific variations of batteries.[154] In the future, Yannam says that the manufacturers will need to work together to develop standardized batteries to allow large-scale recycling.[155] However, automakers are protective when it comes to their specific battery formulations which will complicate a collaborative scheme.

B. *Case Study: Tesla, Inc.*

Tesla is developing a robust recycling process with private companies to reuse and repurpose their used batteries. In North America, Tesla partners with Kinsbursky Brothers, a major stakeholder in Retriev Electronics, and in Europe, Umicore.[156] 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.[157]

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.[158] Creating products and byproducts

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152 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.

153 *Id.*

154 *Id.*

155 *Id.*

156 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.

157 *Id.*

158 Henry Sanderson, *Rise of Electric Cars Poses Battery Recycling Challenge*, FIN. TIMES

results in Umicore reducing carbon emissions by at least 70% compared to a mechanical separation process.[159] 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.[160] Tesla aspires to integrate recycled batteries into their raw materials so they can be reused in battery cells and parts, achieving a closed loop recycling process.[161]

It is important to note that Umicore does not directly recover lithium; instead, lithium becomes part of a mixed byproduct.[162] 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 their own 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.[163] The problem is that there are significant costs, experimental challenges, and safety hazards in testing LIBs.[164] Damaged LIBs in particular carry risks such as thermal runaway, electric shock, and hazardous substance emissions to the workers who handle them.[165] During the actual recycling process, LIBs can explode through radical oxidation.[166] This occurs when lithium metal produced from the battery overcharges and sustains a mechanical shock on exposure to oxygen in the air.[167] The manual dismantling of cathode materials also exposes workers to toxic volatile organic compounds (VOCs).[168] 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

(Sept. 3, 2017), https://www.ft.com/content/c489382e-6b06-11e7-bfeb-33fe0c5b7eaa.

159 *Id.*

160 Kelty, *supra* note 156.

161 *Id.*

162 Joey Gardiner, *The Rise of Electric Cars Could Leave Us with a Big Battery Waste Problem*, THE GUARDIAN (Aug. 10, 2017), https://www.theguardian.com/sustainable-business/2017/aug/10/electric-cars-big-battery-waste-problem-lithium-recycling.

163 Lebov, *supra* note 14, at 90.

164 *Id.*

165 Elibama, *European Li-Ion Battery Advanced Manufacturing for Electric Vehicles*, LI-ION BATTERIES RECYCLING, https://elibama.files.wordpress.com/2014/10/v-d-batteries-recycling1.pdf (last visited Oct. 15, 2018).

166 Ordonez, *supra* note 17, at 198.

167 *Id.*

168 Jiefeng Xiao, *Recycling Metals from Lithium Ion Battery by Mechanical Separation and Vacuum Metallurgy*, 338 J. HAZARDOUS MATERIALS 124, 125 (2017).

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.[169] 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.[170] In response, manufacturers, including GM, Nissan, and Toyota, offer long-term warranties for their battery packs.[171]

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 waste, and decreasing the amount of energy required to create new batteries.[172] 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.[173] 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.[174] 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."[175] 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.[176]

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169 Narula, *supra* note 4, at xvii.

170 *Id.*

171 *Id.*

172 *Id.*

173 2020 STRATEGIC ANALYSIS OF ENERGY STORAGE IN CALIFORNIA, CAL. ENERGY COMM'N, 22 (2011).

174 Gardiner, *supra* note 162.

175 *Id.*

176 *Id.*

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.[177] 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. Accordingly, second use is only estimated to discount battery prices by a maximum of 12%.[178]

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 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 the 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. There are great economic and leadership advantages 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.

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177 Sonoc, *supra* note 2, at 756.

178 Jeremy Neubauer & Ahmad Pesaran, *NREL/CCSE PEV Battery Second Use Project*, U.S. DEP'T OF ENERGY NAT'L RENEWABLE ENERGY LABORATORY 4 (Sept. 2011) https://www.nrel.gov/transportation/assets/pdfs/52626.pdf.