The Road to Recycling: The Foggy Future of Electric Vehicle Batteries

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I. BACKGROUND

A. Climate Change

Climate change, while an ever-expanding definition, refers to the warming of the Earth's climate system.[2] *The term "climate change" is a neologism that has taken on many iterations and forms, including global warming, climate crisis, climate breakdown, and environmental destruction.*[3] *Climate change, itself, is not novel, however. Long before its coinage, humans suspected that human activity affected the climate.*[4] *There is now a growing consensus that human influence is the catalyst causing extensive changes in Earth's atmosphere and meteorology.*[5] *"Human influence" can include deforestation, overpopulation, and pollution; however, there is perhaps no greater contributor to climate change than greenhouse gas emissions.*[6]

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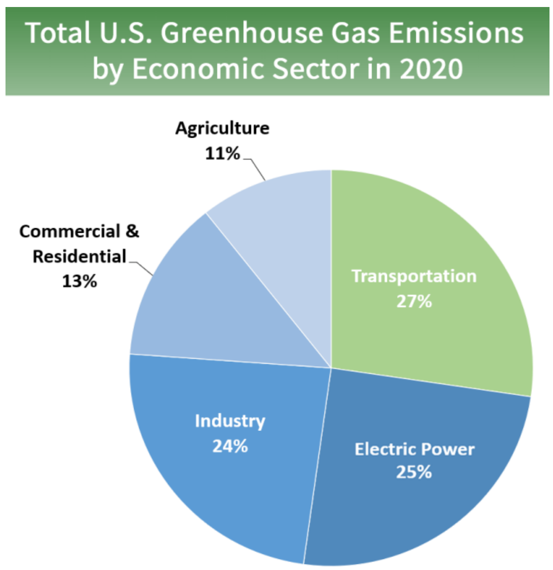
[2] *What is Climate Change,* https://www.un.org/en/climatechange/what-is-climate-change, UNITED NATIONS (last visited Apr. 30, 2023).
[3] Joel Makower, *What's the (Right) Word on Climate Change?*, GREENBIZ (May 19, 2019), https://www.greenbiz.com/article/whats-right-word-climate-change.
[4] Greek philosopher Theophrastus, a pupil of Aristotle, observed how deforestation and mass hunting altered the local ecosystem; Swedish scientist Svante Arrhenius was the first to hypothesize that greenhouse gas emissions correlated with a warming of the Earth's atmosphere. THE DISCOVERY OF GLOBAL WARMING, *Introduction and Summary: A Hyperlinked History of Climate Change Science,* HISTORY.ORG, (Apr. 2022) https://history.aip.org/climate/summary.htm.
[5] M.R. Allen & P.A. Scott, *Estimating Signal Amplitudes in Optimal Fingerprinting, Part I: Theory,* CL. DYN. 21, 477 (Nov. 2003).
[6] *What is Climate Change, supra* note 2.

Greenhouse gases refers to "any gas that has the property of absorbing infrared radiation emitted from Earth's surface and reradiating it back to Earth's surface."[7] *Examples of greenhouse gases include carbon dioxide, methane, and nitrous oxide.*[8] *And while these gases occur naturally, today most greenhouse gases are the direct result of man-made industrialization.*[9]



Natural greenhouse gases cycle through the Earth's atmosphere, with certain amounts preserved within the atmosphere and any remaining quantities ascending into space.[10] *Man-made greenhouse gases have corrupted this equilibrium. Industrialization created an influx of greenhouse gases rising to the Earth's atmosphere, trapping a surplus of heat within the atmosphere.*[11] *In essence,*

[7] Michael E. Mann, *greenhouse gas*, ENCYCLOPEDIA BRITANNICA (Sep. 5, 2022), https://www.britannica.com/science/greenhouse-gas.
[8] *What are Greenhouse Gases,* U.S. DEP'T OF TRANSP. (last updated July 21, 2016), https://www.transportation.gov/sustainability/climate/what-are-greenhouse-gases.
[9] *Sources of Greenhouse Gas Emissions,* U.S. ENV'T PROT. AGENCY, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (last visited May 1, 2023).
[10] *Id.*
[11] *Id.*

greenhouse gases inundate Earth with the very heat that sustains life.[12] *In fact, "human activities are responsible for almost all the increase in greenhouse gases in the atmosphere over the last 150 years."*[13] *This correlation is not coincidental. The advent of the Industrial Revolution two hundred years ago ushered in a new era of human ingenuity, economics, and technology, but with unanticipated costs.*[14] *The Industrial Revolution hinged on the extraction, manufacturing, and burning of fossil fuels.*[15] *Fossil fuel consumption is the leading contributor to releasing greenhouse gases into the atmosphere, making it a substantial factor to the ever-escalating climate crisis.*[16]

Although these environmental impacts were self-evident for decades, it was not until the 1960s that popular, collaborative efforts to reverse these environmental impacts arose.[17] *Since then, the past sixty years witnessed a global, conceded effort to offset centuries of human influence on the climate.*[18] *The objectives of these efforts are predominantly committed to the overall reduction and replacement of greenhouse gas emissions. While these efforts have garnered momentum, the reliance of fossil fuels remains the heart of many national economies.*[19]

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[12] *Id.*
[13] *Id.*
[14] *Industrial Revolution*, ENCYCLOPEDIA BRITANNICA (OCT. 27, 2022), https://www.britannica.com/event/Industrial-Revolution.
[15] Hannah Ritchie, Pablo Rosado, & Max Roser, *Fossil Fuels,* OUR WORLD IN DATA, https://ourworldindata.org/fossil-fuels (last visited Apr. 30, 2023).
[16] *Id.*
[17] Sarah Pruitt, *How the First Earth Day was Born from 1960s Counterculture,* HISTORY (last updated Apr. 21, 2021), https://www.history.com/news/first-earth-day-1960s-counterculture.
[18] *Id.* The environmental grassroots movements of the 1960s spurred U.S. policy, including the founding of the EPA and passage of policies such as the Clean Air Act, Clean Water Act, and Endangered Species Act. *Id.*
[19] *See generally*, *The Evidence is Clear: The Time for Action is now. We can Halve Emissions by 2030,* THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (Apr. 4, 2022),

Electric power, manufacturing, and agriculture are but a few of the examples of private industries contributing to greenhouse gas emissions; however, the "transportation sector generates the largest share of greenhouse gas emissions" in the United States.[20] *Transportation includes any mode in which people and goods are moved.*[21] *While advances in transportation technology engendered greater communication, trade, and cohesion, the carbon dioxide emissions released from gas-based engines subsist as one of the greatest forms of pollution.*[22] *Thus, a leading campaign in climate change mitigation focuses on minimalizing the reliance on gas-fueled vehicles.*[23] *In doing so, this campaign gave rise to a new industry: electric vehicles.*

B. History of Electric Vehicles

An electric vehicle is defined as "a vehicle that can be powered by an electric motor that draws electricity from a battery and is capable of being charged from an external source."[24] Contrastingly, gas-powered vehicle engines are powered by fossil fuels.[25] Gas-fueled vehicles are equipped with batteries as well, but those batteries

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https://www.ipcc.ch/2022/04/04/ipcc-ar6-wgiii-pressrelease/. It warns that greenhouse gas emissions must peak before 2025 and decline accordingly to reduce global warming from 1.5°C. *Id.*

[20] *Sources of Greenhouse Gas Emissions*, *supra* note 9.

[21] *Id.*

[22] *Id.*

[23] David Shepardson & Ben Klayman, *U.S. Government to End Gas-Powered Vehicle Purchases by 2035 Under Biden Order*, REUTERS (Dec. 8, 2021), https://www.reuters.com/world/us/biden-pledges-end-gas-powered-federal-vehicle-purchases-by-2035-2021-12-08/.

[24] *Electric Vehicle (EV) Definition,* DEP'T OF ENERGY, https://afdc.energy.gov/laws/12660, (last visited Apr. 30, 2023).

[25] Christopher G. Foster, Ken W. Purdy & George C. Cromer, *automobile*, ENCYCLOPEDIA BRITANNICA, https://www.britannica.com/technology/automobile, (last visited May 1, 2023).

do not power the vehicle's engine.[26] Rather, gas-fueled batteries simply power the ignition and internal circuits of the vehicle.[27]

While electric vehicles may seem new and innovative, electric vehicles emerged concurrently with gas-fueled cars.[28] Electric vehicles first became available to the public in the late 1890s to early 1900s.[29] By 1912, electric vehicles outnumbered gas-powered vehicles in the United States.[30] However, the electric vehicle industry was soon eclipsed by gas-powered manufacturers.[31] Numerous factors contributed to the decline of electric vehicles, including the limited range of their power, the affordability of gasoline, and inferior speed and power.[32]

For the next century, gas-fueled vehicles dominated the automotive industry.[33] Despite this, electric vehicle experimentation was not totally defunct.[34] Government intervention on climate change prompted manufacturers to research further into electric vehicle sustainability.[35] One of the earliest examples of government intervention was the 1990 California Air Resources Board's proposal to move away from fossil fuel powered vehicles.[36] As a result, companies like Ford and General

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[26] *Id.*
[27] *Id.*
[28] *Id.*
[29] *Id.*
[30] *Id.*
[31] ENCYCLOPEDIA BRITANNICA, *supra* note 25.
[32] *Id.*
[33] *Id.*
[34] *Id.*
[35] *Id.*
[36] The California Air Resources Board was formed to monitor and control air quality in California. *Zero-Emission Vehicle Program,* CALIFORNIA AIR RESOURCES BOARD, https://ww2.arb.ca.gov/our-work/programs/zero-emission-vehicle-program/about (last visited Apr. 30, 2023)

Motors developed electric vehicles.[37] For a time, these efforts remained tentative, with no intention for mass production.[38]

Nevertheless, the phase-out of fossil fueled vehicles only garnered greater attention since the 1990s.[39] For example, the Kyoto Protocol and Paris Agreement represent global efforts to shift away from gas-powered cars.[40] The United States heralded such initiatives, primarily by states introducing legislation that bans the outright sale of gas-powered cars.[41] Perhaps the principal champion of such legislation is California, with the last few years witnessing groundbreaking enterprises to combat climate change. Most notably, California Governor Gavin Newsom issued Executive Order N-79-20 in September of 2020.[42] The order bans the outright sale of fossil-fueled cars by 2035.[43] The initiative is daring, faced with numerous obstacles including industrial reinvention, remodeling state infrastructure, and the unknown economics behind such an undertaking.[44]

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[37] *See* Bradley Berman, *Ford Electric Cars: Past, Present, and Future,* INSIDEEVS (Jan. 22, 2019), https://insideevs.com/features/342330/ford-electric-cars-past-present-and-future/ (Ford spokesperson Tim Holmes noted that "we don't believe that this [electric vehicles] is the future of environmental transport for the mass market"); *General Motors EV1,* Electric Vehicle News, https://electricvehiclesnews.com/History/Companies/General_Motors_EV1.htm, (last visited Nov. 15, 2022).

[38] *See* Berman, *supra* note 37.

[39] Kevin Heanue & Susan B. Petty, *Sustainable Transportation: The Road From Kyoto,* 61 PUBLIC ROADS 5 (1998).

[40] *Id.*

[41] *See generally* Peter Jones, *What States Are Banning Gas Cars,* MOTOR AND WHEELS (Aug. 15, 2022), https://motorandwheels.com/what-states-banning-gas-cars/.

[42] *Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuels in California's Fight Against Climate Change,* OFFICE OF GOVERNOR GAVIN NEWSOM (Sept. 23, 2022), https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/.

[43] Cali. Exec. Order No. N-79-20 (Sept. 23, 2020).

[44] Alvin Powell, *California Dreaming? Nope,* THE HARVARD GAZETTE (Sept. 9, 2022), https://news.harvard.edu/gazette/story/2022/09/what-to-expect-from-california-gas-powered-car-ban/.

Nevertheless, this moment spells a new shift in the electric vehicle movement. Not only this, but the United States may see more states follow suit, with seventeen states proffering similar initiatives.[45]

The advocation for electric vehicles lie in their capability to combat climate change.[46] The focal point of these measures looks at the reduction of greenhouse gases when compared to gas-fueled vehicles.[47] Electric vehicles release no tailpipe pollutants, reducing the reliance of fossil-fuels on the transportation sector.[48] The movement of electric vehicles from gas-fueled vehicles, while not perfect, represents a vital campaign to reduce the effect of human influence on the climate.[49]

However, the shift to electronic vehicles is not without controversy. This skepticism rests in the belief that electric vehicles are merely a procrastination effort to truly combat climate change.[50] Critics particularly highlight the carbon emission burden placed on vehicle production and the generation of the energy needed to power electric vehicles.[51] Electric vehicle production will still require most of the same

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[45] Jones, *supra* note 41. Colorado, Connecticut, Maine, Maryland, Minnesota, New Jerseys, New Mexico, Nevada, Oregon, Pennsylvania, Rhode Island, and Vermont have offered policies similar to California's. *Id.*

[46] Zeke Hausfather, *Factcheck: How Electric Vehicles Help to Tackle Climate Change,* CARBON BRIEF CLEAR ON CLIMATE, https://www.carbonbrief.org/factcheck-how-electric-vehicles-help-to-tackle-climate-change/ (last updated Jul. 2, 2020).

[47] *Id.*

[48] Jeremy J. Michalek et al., *Valuation of Plug-in Vehicle Life-Cycle Air Emissions and Oil Displacement Benefits*, 108 NATIONAL LIBRARY OF MEDICINE, 1 (Sept. 26, 2011), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3189019/.

[49] *Id.*

[50] Jason Henderson, *EVs are not the Answer: A Mobility Justice Critique of Electric Vehicle Transitions*, ANNALS OF THE AMERICAN ASSOCIATION OF GEOGRAPHERS 1 (May 4, 2020), https://www.researchgate.net/profile/Jason-Henderson-3/publication/341138675_EVs_Are_Not_the_Answer_A_Mobility_Justice_Critique_of_Electric_Vehicle_Transitions/links/60199a1345851589397a2c58/EVs-Are-Not-the-Answer-A-Mobility-Justice-Critique-of-Electric-Vehicle-Transitions.pdf.

[51] *Id.*

minerals, elements, and metals needed to produce gas-fueled cars.[52] Additionally, if the global numbers of electric vehicles increase as predicted, "then one third of total global energy would need to be electric."[53] Still, a massive shift to electric vehicle represents a significant reversal of many forms of pollution within the United States.

As of September 2022, there are an estimated 2.5 million electric vehicles on the road in the United States.[54] However, 2.5 million encompasses merely one percent of the total vehicles in the United States.[55] Initiatives, such as California's, are designed to steadily increase these numbers with certain estimates speculating that by 2050, 50% of vehicle sales will be electric.[56] With the expanding electric vehicle industry comes more concerns for environmentally friendly production, maintenance, and disposal.[57] And although electric vehicles developed as a key contributor to reduce greenhouse gas emissions, there remains secondary environmental effects of their production.[58] One such contributor is electric vehicle batteries, the backbone of the vehicle.[59]

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[52] *Id.* at 10.
[53] *Id.* at 9.
[54] Sebastian Blanoc, *Electric Cars' Turning Points May be Happening as U.S. Sales Numbers Start to Climb,* CAR AND DRIVER (Aug. 8, 2022), https://www.caranddriver.com/news/a39998609/electric-car-sales-usa/.
[55] *Id.*
[56] Ira Boudway, *More Than Half of U.S. Car Sales will be Electric by 2030,* BLOOMBERG (Sept. 20, 2022), https://www.bloomberg.com/news/articles/2022-09-20/more-than-half-of-us-car-sales-will-be-electric-by-2030.
[57] Jane Marsh, *Electric Vehicles and Their Impact on the Environment,* BIOFRIENDLY PLANET (Nov. 14, 2022), https://biofriendlyplanet.com/environment-issues/electric-vehicles-and-their-impact-on-the-environment/.
[58] *Id.*
[59] *Id.*

II. GROWING CONCERNS

A. Electric Vehicle Batteries

An automotive battery provides the power to start the gasoline-powered vehicle's engine and provide the electricity flowing within.[60] Automotive batteries, however, were not initially utilized to start engines; engines, originally, started by hand cranking the engine.[61] Batteries simplified this process, storing the power needed to ignite vehicle engines.[62] By the 1920s, automotive batteries, principally lead-acid batteries, were widely used.[63] Today, lead-acid batteries make up the vast majority of the automotive battery industry.[64]

Lead-acid batteries were originally utilized by electric vehicles as well, but their use proved limiting. [65] Simply, lead-acid batteries, especially the size needed for electric vehicles, store lower energy, perform substandard in cold temperatures, and have shorter lifespans.[66] With the electric vehicle sector rapidly growing, lithium-ion batteries emerged as the ideal candidate to replace lead-acid batteries.[67] Lithium-ion batteries now dominate the electric vehicle industry, with nickel-metal-hydride batteries and ultracapacitors close behind.[68] Although more expensive than lead-acid

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[60] *How Does a Car Battery Work and How is it Constructed,* VARTA https://batteryworld.varta-automotive.com/en-gb/how-does-car-battery-work (last visited Apr. 30, 2023).
[61] Andrew Sheldon, *The History of Car Batteries,* THE AMERICAN AUTOMOBILE ASSOCIATION (Feb. 18, 2022), https://magazine.northeast.aaa.com/daily/life/cars-trucks/auto-history/the-history-of-car-batteries/.
[62] *Id.*
[63] *Id.*
[64] *Id.*
[65]*General Motors EV1*, *supra* at note 37.
[66] *Batteries for Electric Vehicles*, DEP'T OF ENERGY, https://afdc.energy.gov/vehicles/electric_batteries.html (last visited Nov. 12, 2022).
[67] Bruno Scrosati *History of Lithium Batteries,* 15 SPRINGER-VERLAG 1623, 1629 (Feb. 23, 2011), https://link.springer.com/article/10.1007/s10008-011-1386-8.
[68] *Batteries for Electric Vehicles, supra* note 66.

batteries to produce, lithium-ion batteries provide higher storage capacity, greater efficiency, and a longer lifespan with slower degradation over time.[69]

Nevertheless, lithium-ion and nickel-metal-hydride batteries are bound to the same environmental issues posed by electric vehicle production.[70] First, electric vehicle batteries are composed of various precious metals and minerals, primarily procured by mining.[71] Mining not only depletes finite metals, but also requires significant amounts of fossil fuels to power these efforts, releasing greenhouse gases repetitiously.[72] Second, the processing of those metals and minerals into the batteries themselves, likewise, require mass amounts of fossil fuels and pollution.[73] After the batteries are created, they are placed in their destined vehicles and run at capacity for the next ten-plus years.[74] Inevitably, however, electric vehicle batteries face their last environmental issue: post-degradation management.[75]

Each electric vehicle battery is subject to varying paces of degradation, depending on the amount of miles covered by an engine over a period of time.[76] However, battery retirement is foreseeable with any electric battery, whether

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[69] *Id.*
[70] *The Environmental Impact of Lithium Batteries,* INSTITUTE FOR ENERGY RESEARCH (Nov. 12, 2020), https://www.instituteforenergyresearch.org/renewable/the-environmental-impact-of-lithium-batteries/.
[71] *Id.*
[72]Andrew Manberger and Bjorn Stenqvist, *Global Metal Flows in the Renewable Energy Transition: Exploring the Substitutes, Technological Mix and Development,* SCIENCE DIRECT 226 (May 2, 2019), https://www.sciencedirect.com/science/article/pii/S0301421518302726.
[73] *Id.*
[74] Leila Ahmadi et al., *Environmental Feasibility of Re-use of Electric Vehicle Batteries,* SCIENCE DIRECT 65, 69 (Jan. 8, 2014), https://www.sciencedirect.com/science/article/abs/pii/S2213138814000071.
[75] *Id.* at 65.
[76] *Id.*

lithium-ion or nickel-metal-hydride.[77] When an electric vehicle battery nears the end of its lifecycle, the electric vehicle enters into its "end-of-life management."[78] That is, the electric vehicle owners are faced with disposing of their battery in a myriad of ways; the batteries can either be thrown out, reused and repurposed, or recycled.[79]

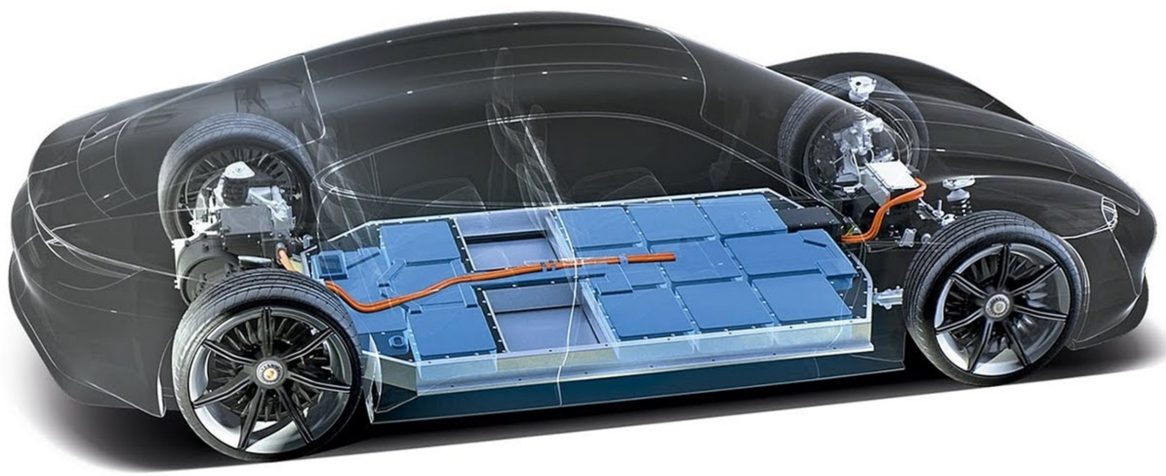
Today, electric vehicle batteries are the most important element of the vehicle. They are a mainstay of environmental efficiencies and gateways to resourceful energy storage. Their disposal represents a new avenue of environmental concerns that has yet to be fully addressed by the government or manufacturers. Battery recycling is one means to reduce the growing environmental impact of electric vehicle batteries.

B. Battery Recycling

Automotive batteries, from lithium-ion to lead-acid batteries, are composed of precious, potentially toxic, metals.[80] Battery metals, themselves, are not necessarily toxic in their existing form, but become problematic when exposed to liquids.[81] In particular, mercury, cadmium, and lead, when exposed to water, may seep into groundwater, contaminating water supplies in local communities.[82] Likewise, mercury, cadmium, and lead, when incinerated, concentrate into fly ash or stack gas,

[77] *Id.* at 63.
[78] *Id.* at 68.
[79] *Id.* at 67-68.
[80] Viet Nguyen-Tien et al., *Green Growth and Electric Vehicles: The Role of Recycling,* LSE BUSINESS REVIEW (July 7, 2022), https://blogs.lse.ac.uk/businessreview/2022/07/07/green-growth-and-electric-vehicles-the-role-of-recycling/.
[81] A.M. Bernardes et al., *Recycling of Batteries: A Review of Current Processes and Technologies,* JOURNAL OF POWER SOURCES 291, 293 (Dec. 8, 2003), https://www.sciencedirect.com/science/article/abs/pii/S0378775303012230.
[82] *Id.* at 293.

polluting air and rainwater.[83] Undoubtedly, landfill disposure increases the chances of liquid exposure to precious metals, with any subsequent incineration spreading exposure over a wider area.[84]



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By the 1980s, environmental and governmental agencies noticed the negative environmental impacts posed by improper battery disposal, especially with growing concentrations of lead in water supplies.[86] As a result, states, municipalities, and cities enacted regulations detailing proper lead-acid battery disposal, moving away from landfill disposal.[87] By siphoning batteries away from landfills, the risks involved with water contamination and incineration were minimized leading into the twenty-first century.[88] However, these regulations were lead-acid battery specific, meaning

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[83] *Id.* Fly ash and stack gas mixes with cloud moisture, polluting groundwater sources with lead if not properly processed.
[84] *Id.*
[85] Stéphane Melancon, *Electric Vehicle Battery Cells Explained,* LASERAX (May 6, 2022), https://www.laserax.com/blog/ev-battery-cell-types.
[86] James Morton Turner, *An Envirotechnical Approach to Lead-Acid Batteries in the United States,* 20 ENVIRONMENTAL HISTORY 29, 30 (2015).
[87] *Id.*
[88] *Id.*

there existed minimal or no regulations for other forms of automotive batteries such as lithium-ion batteries. Although lithium-ion batteries existed by the 1980s, their limited market use and relative obscurity posed no immediate need for scrutiny.[89]

The emergence of lithium-ion and nickel-metal-hydride batteries to power electric vehicles is realigning the environmental microscope.[90] One contributing factor for the lack of recycling efforts is the minimal environmental impact of electric vehicle batteries on water and air pollution.[91] Before their emergence as electric vehicle batteries, lithium-ion batteries were mass produced for small electronic devices.[92] Likewise, lithium-ion batteries do not possess the same amount of potentially toxic metals as lead-acid batteries.[93] Thus, no recycling efforts were likely offered due to the minimal impact these batteries had on the environment compared to lead-acid batteries.

Likewise, recycling is not the first option given to electric vehicle batteries.[94] When an electric vehicle battery has reached the end of its productive life, it still comprises a significant portion of its original capacity potential.[95] At this point, the battery is not powerful enough to power a vehicle, but the battery can be repurposed and reused for services requiring lesser power, including stationary power storage for

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[89] *See generally* Scrosati, *supra* note 67.
[90] *Id.*
[91] Bernardes et al., *supra* note 81, at 292.
[92] Scrosati, *supra* note 67.
[93] *Id.*
[94] Charles R. Standridge & Lindsay Corneal, *Remanufacturing, Repurposing, and Recycling of Post-Vehicle-Application Lithium-Ion Batteries,* MINETA NATIONAL TRANSIT RESEARCH CONSORTIUM 1-2 (June, 2014), https://transweb.sjsu.edu/sites/default/files/1137-post-vehicle-Li-Ion-recycling.pdf.
[95] *Id.*

household items.[96] But this is not an ideal or cost-effective process for manufacturers.[97] Attempting to repurpose an electric vehicle battery requires a detailed analysis of the particular battery's capacity, manpower to disassemble the cells, and refurbishing costs to transform the battery.[98] Nonetheless, even if a battery is repurposed, the battery is either faced with disposal or recycling.[99]

What has yet to be considered in electric vehicle battery recycling, however, is the sheer size and future volume of electric vehicle batteries. Because electric vehicle batteries power the entire engine, the batteries require significant power and storage capacity.[100] Due to this, lithium-ion and nickel-metal-hydride electric vehicle batteries occupy virtually the entire undercarriage of the vehicle. While electric vehicle batteries are not as toxic as lead-acid batteries, their growing number and size pose comparable environmental concerns to lead-acid batteries. Therefore, recycling is a necessary component of all types of battery life cycles.[101] Although recycling in general is a universal process regardless of the waste, lithium-ion batteries require a unique recycling process.[102]

There are three principal methods employed to recycle electric vehicle batteries with varying advantages and disadvantages: pyrometallurgy, hydrometallurgy, and

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[96] *Id.*
[97] *Id.*
[98] Mengyuan Chen et al., *Recycling End-of-life Electric Vehicle Lithium-ion Batteries,* JOULE 3, 2622, 2625 (2019), https://www.sciencedirect.com/science/article/pii/S254243511930474X.
[99] *Id.* at 2623.
[100] *Id.* at 2622.
[101] *Id.* at 2623.
[102] *Id.*

direct recycling.[103] Before any recycling, the batteries are shredded to separate the metals from the plastics and other adhesives.[104] Pyrometallurgy, or "smelting," uses heat to break down batteries into their purest elements and metal compounds.[105] Smelting batteries proves most efficient, as it quickly separates and condenses materials to "black mass," a mixture of valuable metals to be resold.[106] However, smelting raises several environmental concerns, including emissions from greenhouse gases used to power the process.[107]

In contrast, hydrometallurgy use aqueous solutions to "extract and separate metals from batteries."[108] By treating the batteries with organic acids, the metals can be concentrated to their true forms.[109] Hydrometallurgy proves more environmentally friendly than pyrometallurgy because it involves fewer greenhouse gas emissions.[110] Likewise, direct recycling is the process of recovering active metals from the batteries with limited pollution.[111] There, the batteries are moderately heated, sparking chemical breakdowns of the active materials.[112] The minerals are then purified into

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[103] Zachary J. Baum et al., *Lithium-ion Battery Recycling – Overview of Techniques and Trends,* ACS PUBLICATIONS 712, 713-716(Jan. 19, 2022), https://pubs.acs.org/doi/pdf/10.1021/acsenergylett.1c02602.
[104] *Id.* at 714.
[105] *Id.*
[106] Paul Lim, *Black Mass Value Will Increase as Recycling Tech Improves,* FASTMARKETS (Oct. 31, 2022), https://www.fastmarkets.com/insights/black-mass-value-will-increase-as-recycling-tech-improves.
[107] Joanna Kulczycka et al., *Environmental Impacts of Energy Efficient Pyrometallurgical Copper Smelting Technologies,* WILEY PERIODICALS, INC. 304, 305 (Mar., 2017), https://onlinelibrary.wiley.com/doi/pdf/10.1111/jiec.12369.
[108] Baum et al., *supra* note 103, at 714.
[109] *Id.*
[110] Chen et al., *supra* note 98, at 2630.
[111] *Id.* at 2636.
[112] *Id.* at 2635.

their original forms.[113] While direct recycling is the most environmentally friendly, it requires a great amount of manpower to manually dissemble the batteries in addition to complicated chemical issues.[114]

All these forms of recycling provide positive environmental and economic advantages for manufacturers; yet, in 2019 only 5 percent of electric vehicle batteries were recycled.[115] But as the popularity of electric vehicles continue to grow, the industry will confront an influx of batteries facing degradation and end of life management each year.[116] Under current recycling trends, "most of those [lithium-ion] batteries may end up in landfills."[117] The recycling industry will require economic growth to meet recycling demands, but there remains a gap in legislative authority.

Although legislation exists for lead-acid battery disposal, there has been no legislation passed concerning the disposal of electric vehicle batteries. Ergo, manufacturers or producers are free to address this issue as they see fit, whether that is recycling, disposal, or repurposing. Electric vehicle battery legislation has yet to rise to prominence simply because of scale. That is, electric vehicles are still a miniscule number of vehicles on the road today, with many yet to reach the end of their battery capacity. While the problems of electric vehicle battery disposal have yet to come to fruition, the mass-scale disposal of lithium-ion and nickel-metal-hydride batteries is an undeniable future of the electric vehicle industry. With no

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[113] *Id.* at 2636.
[114] *Id.*
[115] Mitch Jacoby, *It's Time to Get Serious About Recycling Lithium-ion Batteries,* 97 CHEMICAL AND ENGINEERING NEWS (July 14, 2019), https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28.
[116] Chen et al., *supra* note 98, at 2622-2623.
[117] Jacoby, *supra* note 115.

recycling plan in place, environmental and economic detriments such as toxic metal pollution, continued over-reliance on mining operations, and waste of natural resources remain at the forefront of the industry's future.

III. SOLUTION

A. Regulations Enacting Change

Environmental regulations require compromise. On one hand, businesses free from the confines of environmental regulations can pursue their economic goals with limited oversight in an arguably already highly regulated sector.[118] On the other hand, environmental regulations have slowed the advancement of unprecedented environmental degradation, leaving an ineffable impact on a fragile ecosystem.[119] Both are true. Admittedly, environmental regulations impose significant costs on businesses.[120] However, to leave businesses to their own devices will inarguably place profits and competition ahead of the welfare of society and the protection of the environment.[121] Therefore, a balance must be struck between constructive environmental regulations and economic feasibility.[122]

Traditional environmental regulations focus on either the production or waste management of goods.[123] For example, the lead-acid battery disposal law in

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[118] *See generally* Juan J. Martinez Hernandez et al., *Business-Oriented Environmental Regulation: Measurement and Implications for Environmental Policy and Business Strategy from a Sustainable Development Perspective,* 30 Business Strategy and the Environment (2020).
[119] *Id.*
[120] *Id.*
[121] *Id.*
[122] *Id.*
[123] Johan Widheden & Emma Ringström, *Life Cycle Assessment,* 2 HANDBOOK FOR CLEANING/DECONTAMINATION OF SURFACES 695 (2007).

Pennsylvania does not regulate how lead-acid batteries are produced.[124] Instead, this law forbids any person, whether an individual or corporation alike, from disposing of lead-acid batteries in landfills.[125] Further, anyone tasked with lead-acid battery disposal must deliver the batteries to a recycling facility preapproved by the Environmental Protection Agency ("EPA").[126] The efficacy of recycling initiatives akin to Pennsylvania's have not been in vain. By implementing such regulations, the United States has witnessed a domestic lead-acid recycling rate of 99%; of which, the "U.S. produced nearly one million tons of recycled lead" in 2021, forwarding the recycled lead to new battery production.[127]

Due to this success, the belief that electric vehicle batteries' disposal should be regulated is growing less to be a question of if, but when.[128] In fact, U.S. Representative Carolyn B. Maloney introduced the Strategic EV Management Act (the "Act") "to streamline the process of recycling and reusing of vehicle batteries from the federal fleet of electric vehicles and move the United States closer to energy independence."[129] The Act does not offer explicit regulations on electric vehicle battery disposal but directs certain agencies to develop plans for future

[124] 53 Pa. Const. Stat. §4000.1510 (1988).
[125] *Id.*
[126] *Id.*
[127] *Recycling Lead-Acid Batteries is Easy. Why is Recycling Lithium-Ion Batteries Hard?,* CLEAN TECHNICA (July 24, 2022), https://cleantechnica.com/2022/07/24/recycling-lead-acid-batteries-is-easy-why-is-recycling-lithium-ion-batteries-hard/.
[128] Jacoby, *supra* note 115.
[129] *Chairwoman Maloney Introduces Legislation to Develop Strategic Plan for Federal Electric Vehicle Battery Management,* HOUSE COMMITTEE ON OVERSIGHT AND REFORM (Sept. 22, 2022), https://oversight.house.gov/news/press-releases/chairwoman-maloney-introduces-legislation-to-develop-strategic-plan-for-federal.

implementation.[130] Likewise, the plan is narrowly tailored to address requirements for federally owned electric vehicles.[131] Thus, the Act is merely a stepping stone to further regulation. Furthermore, the Act is emblematic of what this paper hopes to convey: the need and benefits of electric vehicle battery recycling.

B. Beneficial Effects

Electric vehicle manufacturing, on average, emits more greenhouse gases than conventional car production, chiefly due to electric vehicle batteries.[132] Nevertheless, electric vehicles over the course of their lives, from production to retirement, release significantly less greenhouse gas emissions compared to conventional vehicles.[133] Moreover, battery recycling will steadily lower the carbon footprint of electric vehicles.[134] For example, aluminum comprises approximately 16 percent of a battery cell mass.[135] Batteries composed of recycled aluminum "creates approximately 95 percent less greenhouse gas emissions compared to producing aluminum from natural resources."[136] Overall, recycling efforts can translate to a 7 to 17 percent net reduction in carbon emissions originating from batteries, with certain percentages depending on the metals involved.[137]

[130] Strategic EV Management Act, S. 117-139, 117th Cong. §4057 (2022).
[131] *Id.*
[132] Dale Hall & Nic Lutsey, *Effects of Battery Manufacturing on Electric Vehicle Life-Cyle Greenhouse Gas Emissions,* THE INTERNATIONAL COUNCIL OF CLEAN TRANSPORTATION 1, 5 (Feb. 2018), https://theicct.org/sites/default/files/publications/EV-life-cycle-GHG_ICCT-Briefing_09022018_vF.pdf.
[133] *Id.*
[134] *Id.*
[135] *Id.* at 9.
[136] *Id.* at 8.
[137] *Id.* at 9.

Likewise, recycling will address rising demands for precious metals.[138] One study curated by the Lund University in Sweden proffered that by 2060, mined metals would need to increase by 87,000 percent to supply electric vehicle batteries alone.[139] And as of now, the United States houses no significant reserves or sources of these metals, relying on imports to meet current demands.[140] Recycling regulations will alleviate this supply-chain conundrum.[141] While not an infallible cure, recycling will capture close to 95 percent of nickel, cobalt, lithium, and copper, redirecting their course to further battery production or similar ventures.[142] This will minimize the United States's reliance on foreign mines to extract such metals.[143]

Additionally, recycling "has the potential to reduce primary demand by between approximately 25 percent and 55 percent of total demand in 2040 and can significantly reduce the demand for new mining."[144] By supplying battery production through recycling as opposed to extracting untouched materials, the need for mining will lessen.[145] Certain estimates have indicated that recycling will reduce mining demand for metals: "approximately 25% for lithium, 35% for cobalt and nickel, and 55% for copper."[146] This is not to say that mining will dissipate, but as metal sources

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[138] *Reducing New Mining for Electric Vehicle Battery Metals,* EARTHWORKS 1 (Apr. 27, 2021), https://earthworks.org/resources/recycle-dont-mine/.
[139] Manberger and Stenqvist, *supra* note 72, at 230.
[140] *Lithium-Ion EV Battery Recycling Policy Framework,* ALLIANCE FOR AUTOMOTIVE INNOVATION 1, 3 https://www.autosinnovate.org/posts/energy-environment/Lithium-Ion%20EV%20Battery%20Recycling%20Policy%20Framework.pdf (last visited Nov. 30, 2022).
[141] *Id.*
[142] Jim Motavalli, *Closing the Loop on EV Battery Recycling,* SAE INTERNATIONAL (Oct. 7, 2022), https://www.sae.org/news/2022/10/ev-battery-recycling.
[143] *Id.*
[144] *Reducing New Mining for Electric Vehicle Battery Metals*, *supra* note 138, at 28.
[145] *Id.*
[146] *Id.*

lessen and lessen, the need for sustainable metal sources will prove valuable over time. These considerations are dependent on making recycling a compulsory component of battery conservation.[147]

C. Tackling Critiques

i. Regulation as a Hindrance

Nevertheless, environmental regulations are not immune from scrutiny.[148] Numerous factors contribute to alleged, and often valid, shortcomings of environmental regulations, including ineffective implementation, economic degeneration, and unfair competition.[149] With particular attention on electric vehicles and their batteries, some offer that the industry will slip into these same shortcomings.[150] Indeed, recycling electric vehicle batteries will place significant financial burden on manufacturers.[151] Transportation alone may amount to 40 percent of the overall cost associated with these efforts.[152] Nevertheless, regulatory pitfalls are suspect at best.[153]

While regulations may be restrictive, if the decision to recycle is left solely to the discretion of manufacturers, then the potential environmental and economic

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[147] *Id.*
[148] Antoine Dechezlepêtre & Misato Sato, *The Impacts on Environmental Regulations on Competitiveness,* 11 Review of Environmental Economics and Policy (2017).
[149] *Id; see also* De Vann Sago, *The Difficulties of Enforcing Global Environmental Law,* GEORGETOWN ENVIRONMENTAL L. REV. (Feb. 1, 2019), https://www.law.georgetown.edu/environmental-law-review/blog/214/.
[150] Gregory Barber & Aarian Marshall, *Cars are going Electric. What Happens to the Used Batteries?,* WIRED (Nov. 2, 2021), https://www.wired.com/story/cars-going-electric-what-happens-used-batteries/.
[151] *Id.*
[152] *Id.*
[153] *Id.*

upsides of recycling will go unrealized.[154] In actuality, "many recyclers downcycle their material to a grade unable to be used for electric vehicle battery manufacturing."[155] Implementing a zero-exception policy in recycling will reverse such practices.[156] One need not look further than the effectiveness of lead-acid battery recycling.[157] Additionally, manufacturers and producers may be hit with short-term costs but profit from long-term gains.[158] Recycling addresses issues of "material insecurity and commodity price volatility," directing the market inward and reducing the need for further metal purchases.[159]

ii. Recycling Plant Pollutants

Recycling is often considered an unalloyed benefit.[160] An unforeseen side effect offered by some critics is contamination runoff from recycling plants, the very facilities burdened with avoiding pollution.[161] Some domestic manufacturers have circumnavigated government inspections by exporting batteries to foreign plants.[162] The result has been lead and other metal pollution in water sources, sickening the

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[154] Lauren Fricke, *The Long-Term Problem with Electric Vehicle Batteries: A Policy Recommendation to Encourage Advancement for Scalable Recycling Practices,* 12 SEATTLE J. OF TECH., ENVIRONMENTAL, AND INNOVATION LAW 27, 43 (2022).
[155] *Id.*
[156] *Id.*
[157] Lauren Neahaus, *The Electrifying Problem of Used Lithium Ion Batteries; Recommendations for Recycling and Disposal,* 42 ENVIRONS 65, 76 (2019).
[158] Viet Nguyen-Tien et al., *supra* note 77.
[159] *Id.*
[160] Fred Pearce, *Getting the Lead Out: Why Battery Recycling is a Global Health Hazard,* YALE ENVIRONMENT 360 (Nov. 2, 2020), https://e360.yale.edu/features/getting-the-lead-out-why-battery-recycling-is-a-global-health-hazard.
[161] *Id.*
[162] *Id.*

local residents.[163] While this issue has plagued foreign recyclers especially, the growing demand for battery recycling could retrospectively affect the U.S. as well.[164]

Largely, the U.S. holds its head above the rest for proper recycling efforts.[165] That does not mean though that the U.S. is immune to such devices. For regulation to prove successful, the onus must be placed on electric vehicle producers.[166] Producers should be responsible for "the collection, treatment, recycling, and disposal of batteries in proportion to their market share."[167] To comply with such regulations, the EPA should ensure that manufacturers and producers keep accurate records of their processes and send retired batteries to proper, licensed, and approved recycling plants.[168] There could also exist pecuniary incentives such as a buy-back option for recycled metals, allowing manufacturers to purchase recycled metals in proportion to the retired batteries shipped.

Additionally, transparency between the government, private sector, and consumers can prove paramount for corporate accountability.[169] Providing notice to residents within the vicinity of a treatment facility will promote greater public awareness.[170] Consumers have proved successful in holding recycling plants accountable in the past. In 2013, residents of Vernon, California, raised concerns about pollution stemming from a lead-acid recycling plant operated by Exide.[171] The

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[163] Pearce, *supra* note 160.
[164] *Id.*
[165] *Id.*
[166] Neahaus, *supra* note 157, at 85.
[167] *Id.*
[168] *Lithium-Ion EV Battery Recycling Policy Framework, supra* note 140, at 6-7.
[169] Neahaus, *supra* note 157, at 87.
[170] *Id.*
[171] *Id.* at 78-79.

South Coast Air Quality Management District investigations concluded that Exide pollutants from the Vernon plant threatened 110,000 residents.[172] There, the consumers and government working in tandem, exposed Exide for its lackluster pollution efforts and, as a result, obliged Exide to clean up toxic waste.[173]

IV. THE REGULATION

Electric vehicle battery regulation is not only likely but a necessary future for the United States.[174] The need for federal regulation is paramount for ensuring recycling produces positive environmental and economic results nationwide.[175] But for the purposes of this solution, the regulation should be eased into on a state level. While the need for federal regulation is inevitable, "states can be an important catalyst for federal action."[176] In doing so, Pennsylvania can become a trailblazer, taking the lead from states like California to initiate regulation.

Pennsylvania should enact a statewide electric vehicle battery law not so different than Pennsylvania's current lead acid battery regulation, 53 Pa. Stat. §4000.1510. However, Pennsylvania's regulation should be broader than the lead-acid battery law. That is, the Pennsylvania law should address the need for proper disposal and recycling of electric vehicle batteries in general and not simply limit its reach to lithium-ion batteries. The regulation should forbid the disposal of any

[172] *Id.*
[173] *Id.*
[174] Robert Bird et al., *The Regulatory Environment for Lithium Ion Battery Recycling,* 7 ACS ENERGY LETTERS 736, 737 (2022).
[175] *Id.*
[176] Neahaus, *supra* note 157, at 66.

electric vehicle battery, or component, in a landfill. Instead, electric vehicle batteries must be recycled in a preapproved recycling plant.

Additionally, the cost will be placed on the manufacturers, not consumers, to ensure electric vehicle batteries are recycled. To ensure compliance, automotive manufacturers will be charged with documenting these transactions, promptly notifying the Pennsylvania Department of Environmental Protection ("Pennsylvania DEP") of their efforts. Likewise, the Pennsylvania DEP will provide oversight on such efforts. Principally, the Pennsylvania DEP will inspect sites and premises governed by the proposed regulation. Furthermore, the Pennsylvania DEP will be empowered to sanction or cite those who fail to comply with these requirements. It should be noted, however, that this regulation serves as a starting point. Technological innovations, especially in the automotive industries, may prove difficult to legislate. Therefore, a Pennsylvania regulation will have to be crafted to conform with technological advances and economic incentives; more likely, the regulation would need to be a cooperative effort between the regulators and manufacturers to hold this regulation to its highest potential.

V. CONCLUSION

Simply put, the economic and environmental advantages of recycling outweigh the irrecoverable costs currently accepted by automotive manufacturers. Recycling regulation will not only reduce carbon emissions stemming from the transportation industry, but also preserve valuable metals and minerals within the United States, thereby avoiding over-reliance on foreign suppliers to meet current and future demands.[177] Manufacturers, consumers, and the government can waste no time delaying this issue any further. The deficiency of electric vehicle battery recycling has no vast consequence as of now but will become more self-evident with time. Recycling's long-term advantages must be seriously considered to maximize its long-term gains. Now is the time for regulation.

[177] *Id.* at 74.