Electric Vehicle (EV) Battery Management Study

Preliminary Report to the Legislature Pursuant to Engrossed Second Substitute Senate Bill 5144 (2023)

By

Peak Sustainability Group

For the

Solid Waste Management Program

Washington State Department of Ecology

Olympia, Washington

October 2023

PEAK SUSTAINABILITY

Publication Information

Cover photo credit

- Smile Fight/Shutterstock

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Executive Summary

In 2023, the Washington State Legislature passed a law creating a comprehensive battery stewardship program. As part of this law, the Washington State Department of Ecology is required to research the management of electric vehicle batteries and provide the Legislature with a preliminary report in November 2023 and a final report in April 2024.

The preliminary report focuses on the findings of the research and initial stakeholder input. Additional engagement efforts are planned for January of 2024 to ensure that there is effective and balanced stakeholder representation in the priorities and information presented to the Legislature. The preliminary report does not provide policy recommendations for EV battery management in recognition that effective recommendations depend on allowing adequate time for stakeholders to inform priorities and share concerns. Recommendations will be presented in the final version of this report.

The Electric Vehicle (EV) Battery Management Study Preliminary Report to the Legislature lays out preliminary findings and examples from other jurisdictions, and identifies remaining questions related to EV battery management. The report addresses critical questions related to end-of-life pathways for EV batteries, volume and projections of end-of-life EV batteries, relevant regulations, economic implications, and considerations pertaining to battery chemistry. The goal is to identify ways Washington state can support a robust EV battery management system in Washington state. Research was conducted through a combination of literature reviews, case studies, and stakeholder engagement efforts, including interviews, webinars, and a survey.

In the first six months of 2023, 18% of cars sold in Washington state were EVs, making Washington state one of the leaders in EV adoption in the U.S. As existing EV batteries age, the number of EVs that reach end-of-life will increase in Washington. The preliminary report shares initial findings regarding the various pathways EV batteries take when they no longer function within a vehicle and discusses the factors that determine what happens to EV batteries. Throughout the report, knowledge gaps are stated. Some knowledge gaps may be addressed in the final report, while certain knowledge gaps are not possible to address now.

The growing market share of EVs will require a system of management that fosters innovation, moves forward state climate change goals, promotes responsible product stewardship, and supports safety for communities and the environment. Both state and federal regulations and codes apply to the collection and management of EV batteries in Washington state. The preliminary report provides an overview of these regulations which are co-evolving with industry developments and communities. Careful consideration is needed for actions at the state and federal level.

Industry stakeholders have shared concerns that a patchwork of regulations across states and the federal government could make effective management of EV batteries prohibitively expensive. Safety and efficiency are priorities for many stakeholders. There is broad interest in finding ways to support emergency responders in managing incidents involving EVs and EV batteries. Information on what companies and organizations exist to cost-effectively collect, manage, recycle, reuse, or properly dispose of EV batteries could support local stakeholders and smaller industry stakeholders in a rapidly evolving landscape.

Introduction

Legislative directive

In 2023, the Legislature adopted Engrossed Second Substitute Senate Bill 5144[3] to provide for responsible environmental management of batteries and support a battery stewardship program. Section 17 of the bill also requires research on the management of electric vehicle batteries, stakeholder engagement, and delivery of recommendations to the Legislature via a preliminary legislative report in November 2023 and a final report in April 2024.

The Washington State Department of Ecology Solid Waste Management Program (Ecology) hired Peak Sustainability Group, with sub-consultants GDS and Stikeen Strategies, (the Consultant Team) to complete electric vehicle battery research and stakeholder engagement, as well as develop policy recommendations for the Legislature's consideration. This preliminary report focuses on findings from electric vehicle battery research and stakeholder engagement. Policy recommendations will be included in the final legislative report.

"Electric vehicle (EV)"

In this report, an EV 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. [4] An EV includes both a vehicle that can only be powered by an electric motor that draws electricity from a battery (all-electric vehicle) and a vehicle that can be powered by an electric motor that draws electricity from a battery and by an internal combustion engine (plug-in hybrid electric vehicle – PHEV). For the purposes of this report, 'vehicle' is limited to a means of transportation on roads.

"End-of-life (EOL)"

When referring to EV batteries in this report, the term "end-of-life" is defined as the moment where a battery reaches the end of its usefulness and/or lifespan, as originally manufactured, in an EV.

Many other terms are used in this report, some of which may be new to reviewers. Key definitions associated with this report are found in Appendix A, and acronyms are listed in Appendix B.

EV battery supply chain and lifecycle

The supply chain and lifecycle of EV batteries is important to understand because decisions made at various points in that cycle affect the management of EV batteries during their end-of-life. A high-level overview of the life cycle of EV batteries is broken down into steps below.

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[3] https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/Session Laws/Senate/5144-.pdf?q=20231003145449.
[4]https://afdc.energy.gov/laws/12660#:~:text=An%20EV%20is%20defined%20as,charged%20from%20an%20external%20source.

Step one: product design

EV batteries are designed for their specific use in an electric vehicle, usually for a specific make and model of car. This design process can affect the following steps depending on battery chemistry, other constituent materials, and the manufacturing process.

Step two: mining for a battery's active materials

An EV battery's constituent active materials (materials used for the exchange of ions to discharge and charge the battery) are first mined. Different battery chemistries have differing active materials including lithium, cobalt, nickel, iron, graphite, and more. Each of these minerals are mined in different regions across the world. As an alternative to mining for these materials, there is a growing interest in recovering the materials from used batteries and recycling them for reuse in battery manufacturing.

Step three: material processing and refining

After mining or recovering the needed materials, an EV battery's constituent materials are processed and refined. Much of this processing occurred in China until the Inflation Reduction Act (IRA) was passed. This has sparked investment and growth in the U.S. battery market.

Step four: product manufacturing

An EV battery's constituent materials are manufactured into the final functioning battery that is ready to be put to its intended use powering an electric vehicle.

Step five: product installation and use

EV batteries are professionally installed by auto manufacturers before the electric vehicle is put on the market and sold to a driver. The EV lives out its first life on the road, powering the car as intended. EV batteries may require periodic maintenance and service by dealerships during the warranty period and may involve private or do-it-yourself repair after the warranty is expired.

Step six: battery removal

A battery's first life ends when it is removed from its original electric vehicle for any reason, including vehicle damage from a collision, fire, or flood, and removal when the battery no longer functions as intended in the vehicle. Training and special equipment is generally required for the removal of an EV battery, as they can weigh over 1000 pounds. Steps six through eight are considered an EV battery's 'end-of-life' for the purposes of this study and report.

Step seven: end of first life battery repair, resale, reuse, repurposing, possible storage, and stockpiling

After a battery is removed from the original vehicle, it may be transported to the subsequent owner, or it may be stored or stockpiled before a second life. Resale after repair (if necessary) can lead to reuse in other EVs, EV conversions, and/or repurposing in non-EV applications, such as grid storage systems [5].

Step eight: recycling, disposal, and abandonment

Ultimately, an EV battery is recycled, or in some cases disposed of or abandoned.

Evolution of EVs and EV batteries

It is helpful to have a high-level understanding of the evolution of electric vehicles and batteries to underpin the information in this report. This section provides a brief overview of the history of EVs and EV batteries up to this point.

A brief history of EVs

Electric vehicles date back to the 1830s, with the introduction of rechargeable batteries in the 1850s. With the exception of a brief experiment with EVs in the 1990's, commercially available EVs have not been part of the automobile marketplace until relatively recently. With the growing understanding of climate change and the recognition that EVs are cost effective alternatives to cars with internal combustion motors, EV sales are rapidly expanding in many parts of the country. Washington state is one of the leaders in EV adoption.

Battery technology has evolved rapidly since 2010 with different battery chemistries and formats. High-capacity manufacturing has boosted battery availability while also reducing costs. This is a key to ramping up EV production. Battery chemistries are evolving as well resulting in batteries that contain less content of materials like cobalt and nickel that are problematic to secure and process. This is a factor in driving down costs.

Commercial car companies are investing billions of dollars in U.S. production sites due to the Inflation Reduction Act which prioritizes U.S. production and mineral sourcing and processing from allied countries. Production of batteries in the U.S. is highly dependent on sources of recycled materials. Battery recycling companies operating in the U.S. currently receive the bulk of their recycled materials from battery OEM's scrap.

[5] U.S. Department of Energy: Battery Storage: https://www.energy.gov/eere/vehicles/battery-policies-and-incentives-search.

EV Battery Management Study Overview

As directed by Section 17 of Engrossed Second Substitute Bill 5144[6] and the Washington State Department of Ecology (Ecology), the consultant team has been conducting the EV Battery Management Study (the Study). The Study is focused on:

- Gathering information about current EV battery management practices in Washington and other jurisdictions; and
- Engaging with stakeholders (i.e., automotive recyclers, solid waste companies, battery recyclers, local governments, environmental organizations, electric vehicle manufacturers, and others), to gather further information on the management of EV batteries in Washington.

These tasks have informed this preliminary report to the Legislature, which is focused on process, current findings, emerging themes, and key knowledge gaps regarding EV battery management in Washington state.

The consultant team will continue this research and stakeholder engagement throughout the second phase of the Study to fill knowledge gaps and inform policy recommendations to the Legislature, which will be included in a final legislative report in April 2024.

Key questions

The consultant team was asked to conduct a literature review and engage with stakeholders to gather more information on the below key questions about EV battery management in Washington state and other jurisdictions.

Volume and projections

- What is the estimated volume of EV batteries currently being collected in Washington?
- What is the ten-year projection for EV batteries requiring end-of-life management?

Regulations

- What regulations govern the collection, transportation, storage, processing, and recycling of EV batteries in Washington state?

Common post-first-life and end-of-life pathways

- What second-life use-cases exist for EV batteries?
- What are the common pathways for EV batteries at their end-of-life?
- What happens to EV batteries after they are collected?
- Where are EV batteries stored or stockpiled once they are removed from vehicles?

[6] https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/Session Laws/Senate/5144-S2.SL.pdf?q=20230525111908.

- At what facilities might storage occur?

Economics of battery management

- What is the financial landscape surrounding EV batteries?
- Are there existing programs that provide funding or incentives for EV battery management?

Battery chemistry and value

- What characteristics and values are associated with the most common EV battery chemistries?

Literature review methodology

The literature review conducted by the consultant team played a critical role in answering the key questions stated in the section above. The literature review process and steps included:

- Searching existing articles, academic research papers, industry reports, governmental publications, online databases, and business websites to gather information on the current system for collecting and managing EV batteries. The search included, but was not limited to, regulations, policies, and guidelines that apply throughout the battery lifecycle. The consultant team made an effort to be as comprehensive as possible in order to ensure that all relevant studies, published and unpublished, are included in the review.
- Screening the literature, papers, reports, and publications to determine their relevance to the key questions. The researchers devised a set of guiding rules to include or exclude certain studies and therefore avoid biases.
- Extracting applicable information from each study and determining its relevance to the key questions.
- Synthesizing information by summarizing, organizing, and comparing details across various papers, reports, and publications.

The consultant team leveraged their industry connections to conduct a comprehensive and exhaustive literature review on the current system for collecting and managing EV batteries. Case studies from other states, jurisdictions, and industry leaders were collected and analyzed to identify successful EV battery collection and management best practices, approaches, policies, infrastructure, and programs. The literature review findings effectively captured current knowledge of key activities and outcomes related to EV battery management.

Stakeholder process and participation

Engrossed Second Substitute Bill 5144, Section 17, Subsection 2 requires the Study to "solicit input from representatives of automotive wrecking and salvage yards, solid waste collection and processing companies, local governments, environmental organizations, electric vehicle manufacturers, and any other interested parties."

The consultant team has been engaging stakeholders throughout the Study using the methods outlined below. Stakeholder engagement is ongoing and will inform the final legislative report.

Project web page

Ecology created a web page for information and stakeholder engagement opportunities related to the Washington State EV Battery Management Study. The webpage provides an overview of the Study, along with dates, details, links, and contact information for stakeholder engagement opportunities. EV Battery Management Study Webpage[7].

Stakeholder outreach

The consultant team sent email invitations to representatives of over one hundred potentially interested stakeholder groups and organizations to invite them to participate in interviews, a survey, and two webinars. The invitation also encouraged contacts to invite any other interested stakeholders into the Study process.

Participating stakeholders

The consultant team obtained input from a variety of potentially interested parties, including:

- Representatives from the Auto Recycling and Metal Recycling sectors
- State government staff in Energy Policy, Hazardous Waste, Economic Development
- WA city and county representatives, including those within solid waste management
- Companies that directly recycle EV batteries or collect and transport them for recycling
- Companies that recycle non-EV batteries
- WA state first responders and representatives
- Representatives for legacy and EV-only automakers
- Battery Original Equipment Manufacturers
- Participants in the EV battery reuse market
- EV Policy advocacy organizations
- Environmental advocacy organizations

Interviews

The consultant team conducted interviews with industry stakeholders, including representatives from the above stakeholder groups. These interviews informed the literature review, answered key questions, and identified knowledge gaps to investigate further. Example interview questions can be found in Appendix D. Interviews with stakeholders are ongoing and new information and perspectives will be included in the final report.

[7] https://ecology.wa.gov/waste-toxics/reducing-recycling-waste/our-recycling-programs/battery-stewardship.

Webinars

The consultant team conducted two webinars to gather stakeholder input and identify key gaps in the research. A webinar was held on Tuesday, September 26, 2023, to gather information from participants holding key knowledge on the collection, management, and transportation of EV batteries. Attendees were asked questions related to the collection and management of EV batteries and had the opportunity to share their perspectives.

Another webinar was held on Thursday, September 28, 2023 for stakeholders who may be impacted by an EV battery management system or were interested in sharing their priorities. Attendees were asked questions related to their knowledge and priorities for the collection and management of EV batteries in Washington state.

Survey

The consultant team designed and administered a survey focused on EV battery policy feedback and information gathering focused on the key questions for EV battery management in Washington state. The deadline to provide input for inclusion in the preliminary legislative report was September 29, 2023. The survey will remain open, and responses received by January 31, 2024 will be included in the final legislative report. Respond to the EV Battery Management Survey[8].

Email list

Ecology created an email list for the EV Battery Management Study and the greater implementation of the battery stewardship bill. To receive updates on the EV battery study or the battery stewardship program, please sign up for our email list[9].

Next steps

Next steps in the EV Battery Management Study focus on soliciting stakeholder feedback on the preliminary findings in this report and gathering information to fill key knowledge gaps identified in this report. The consultant team will do this by:

- Continuing to conduct interviews with stakeholders involved in or potentially affected by EV battery management systems, including community-based organizations, local governments, and environmental groups;
- Continuing to gather input through the EV Battery Management Survey; and
- Hosting a second round of stakeholder engagement opportunities to gather information and input on policy recommendations.

These next steps will continue to inform the Consultant Team's understanding of the current EV battery management system in Washington state and form the basis for policy recommendations that will be included in the final legislative report.

[8] https://qualtricsxmmnbfw26d2.qualtrics.com/jfe/form/SV_djtC1QaRhSogl82.
[9] https://public.govdelivery.com/accounts/WAECY/subscriber/new?topic_id=WAECY_303.

To stay engaged in the second phase of the EV Battery Management Study, please see the links below.

- Webpage for EV Battery Management Study
- Email list for EV Battery Management Study and battery stewardship program
- Survey for EV Battery Management Study

Preliminary Findings: Literature Review

As directed by Ecology, the consultant team conducted a comprehensive literature review on the current system for collecting and managing EV batteries. The findings below address the key questions laid out in the EV Battery Management Study Overview section earlier in this report. Each section addresses a theme related to EV battery management and provides a summary of key takeaways, an overview of findings to date, and remaining knowledge gaps to prioritize in the second phase of the Study.

Volume and projections

This section of the literature review provides preliminary findings on the current volume of EV batteries reaching end-of-life, as well as projections for the future. Factors that contribute to end-of-life EV battery projections are also discussed. Existing knowledge gaps are covered at the end of the section. This section is guided by the following questions, as directed by Ecology.

- What is the estimated volume of EV batteries currently being collected in Washington?
- What is the ten-year projection for EV batteries requiring end-of-life management?

Key takeaways

- The volume of EVs is increasing exponentially in WA, and currently the majority of EV batteries are under warranty in their original vehicle.
- As of July 2023, there are 104,050 all-electric vehicles registered within Washington and this number is increasing exponentially.
- Knowledge gaps make it difficult to estimate the number of end-of-life EV batteries currently collected in Washington and, therefore, it is challenging to project what that number will be in 10 years.
- Batteries may be reused or repurposed for 15-18 years after their use in their original vehicle, which could delay when they need to be recycled or disposed.
- Industry is investing in domestic recycling sites to manage projected future increases in end-of-life EV batteries, based on the growing market share of EVs and the demand for materials to create new batteries.

Findings to date

There are multiple factors to consider when estimating the number and type of EV batteries that are being recycled or disposed of in Washington state now and in the next ten years. These factors include the length of time batteries will remain in the original EV, the average length of an EV battery's second life or third life, and the number of EVs that experience an incident that takes them out of use, such as a car accident, recall, fire damage, or flood damage. The unknowns in some of these factors make volume estimates difficult. The following factors that influence volume estimates are discussed:

- The current number of EVs in Washington state.

- Projected EV sales volumes in Washington state.
- The length of time that EV batteries remain in the original vehicle.
- EV battery second and third life.

The number of EVs in Washington state

The Washington Department of Licensing [10] tracks the number of EVs registered in Washington state. As of July 2023, there are 104,050 all-electric vehicles registered within Washington. The majority of EVs on the road will continue to be newer vehicles until the market reaches maturity. Using this number and EV sales forecasts, it is possible to estimate the number of future EVs in Washington.

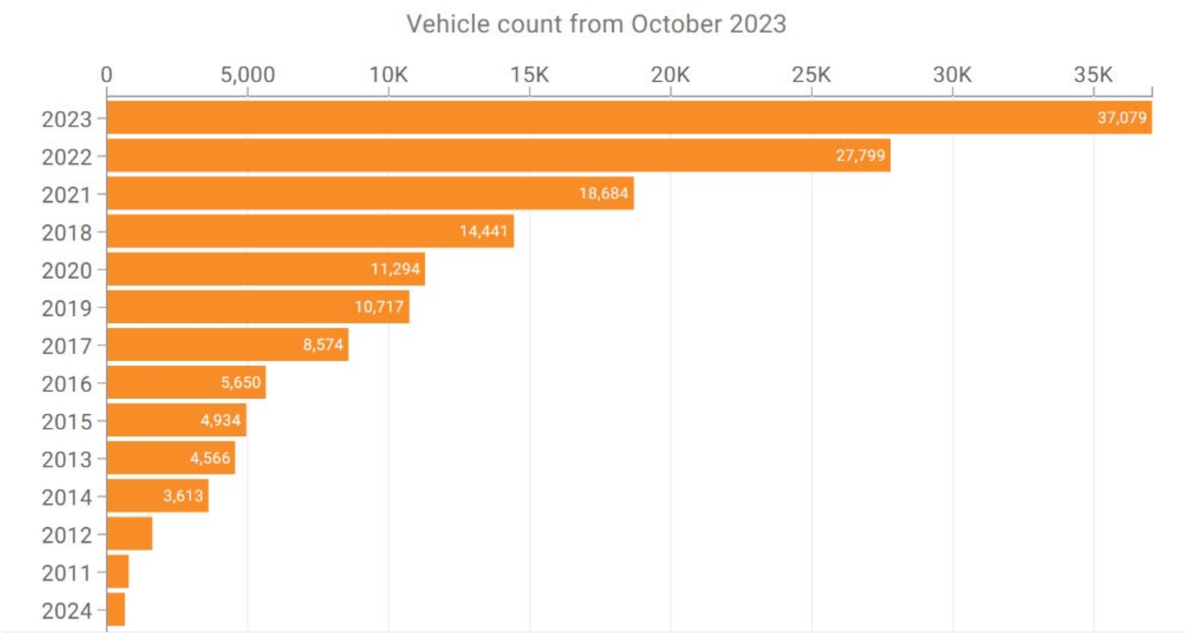

Figure 1. Washington EV population by model year[11].

Projected EV sales volumes in Washington state

The market share of EVs is increasing in Washington and across the country. Large OEMs are In the first half of 2023, EVs were 18% of new car sales in this state. investing in EVs to offer mainstream consumers a wide array of EV choices. These shifts in the market contribute to exponential growth seen in the EV market, but there is a large amount of uncertainty. The draft Washington State Transportation Electrification Strategy projects that by 2035, the number of plug-in EVs in Washington state could range from 1.8 million to 3.8 million EVs.[12]

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[10] https://data.wa.gov/Transportation/Electric-Vehicle-Population-Data/f6w7-q2d2.
[11] https://data.wa.gov/d/f6w7-q2d2/visualization.
[12] Draft Washington State Transportation Electrification Strategy, pg. 55.
https://deptofcommerce.app.box.com/s/1ydxw10qsnygn3gosz5en75zxsj6pso5

Knowledge gaps regarding the length of time an EV battery remains in its original vehicle, as well as the length of its second or third life makes it difficult to know when the projected number batteries in EVs Washington will require end-of-life management.

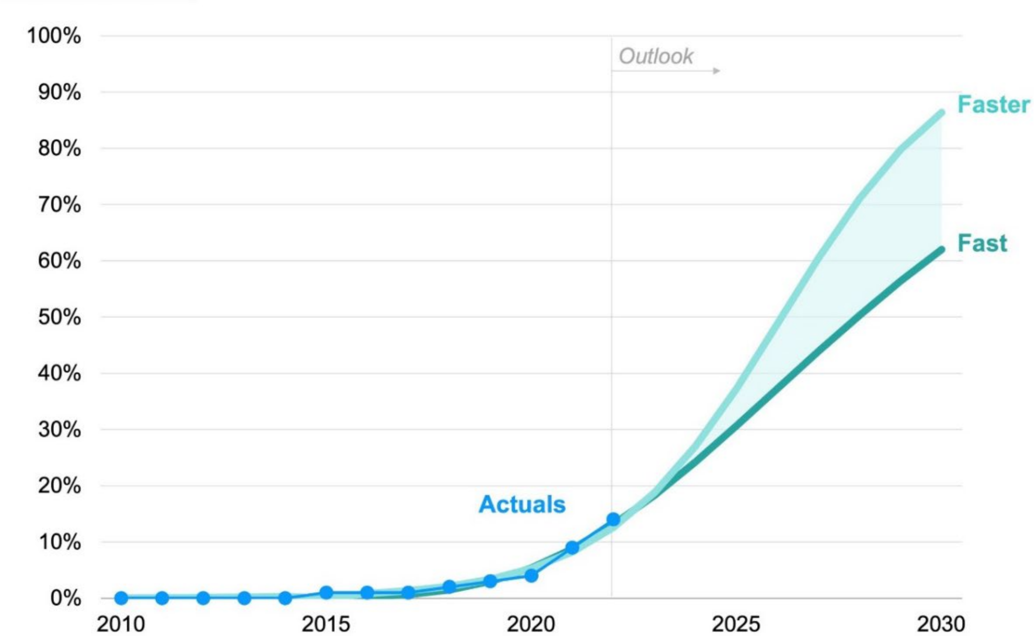

Figure 2. Rocky Mountain Institute's global EV sales projections[13].

The length of time that EV batteries remain in the original vehicle

Global EV battery data indicates that EV batteries last on average 15-18 years before vehicle end-of-life, with many batteries lasting up to 21 years in the original vehicle.[14] OEMs and companies that specialize in refurbishing batteries and are extending the life of battery packs. Battery technology has advanced rapidly over the last decade. Modern lithium iron phosphate (LFP) batteries may last up to twenty years.

Vehicle incidents such as collisions, fires, or floods may shorten the time that an EV battery remains in the original vehicle. In cases where the battery is damaged in the incident, the battery may be recycled or disposed of. The consultant team is researching the rate of EV incidents in WA state, but currently the number is unknown.

[13] IEA, https://rmi.org/insight/x-change-cars.

[14] Circular Energy Storage – at 7:18 of the video, Hans Eric Melin, November 4, 2021, https://youtu.be/czwuxBnPIGY.

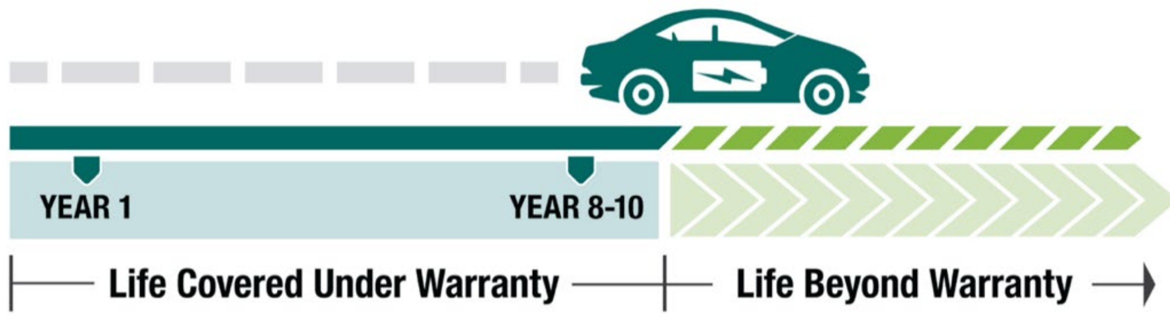

Figure 3. Full first life of an EV Battery generally lasts beyond warranty[15].

EV battery second and third life

After use in the original vehicle, EV batteries may have a second life, and, in some cases, a third life. There is a market for battery reuse that leads to a number of EV batteries being reused in other vehicles, repurposed for use in boats and RVs, or used as stationary grid storage. The number of EV batteries being reused and repurposed is difficult to estimate because these pathways occur in a distributed system that involves many stakeholders.

There is a do-it-yourself (DIY) community within Washington state that reuses EV batteries for EV conversions and other purposes. In EV conversions, an internal combustion engine (ICE) vehicle is modified to become an electric vehicle. The DIY community purchases EV batteries from insurance auctions either within Washington state or from auction sites in other regions of the United States. These batteries are generally being auctioned within a vehicle, and in cases where they are purchased from other regions in the United States, they are shipped to Washington state. The Seattle EV Association (SEVA)[16] is an example of an organization that has connections to the DIY community within Washington state. The number of EV batteries in Washington state that are in use by the DIY community is unknown.

A number of companies are developing energy storage systems using post-first life EV batteries. The State of California offers incentives to this emerging industry via the California Energy Commission (CEC). EV batteries used for energy storage systems may have a second or third life that lasts 5-20 years. While the number of batteries entering second and third life is not known, there is high demand for these batteries.

[15] Call2Recycle. https://www.call2recycle.org/.
[16] Seattle EV Association (SEVA), https://www.seattleeva.org/wp/.

Figure 4. B2U's UL certified EV Pack Storage (EPS) System enables the use of EV battery packs without reconfiguration in large scale energy storage[17].

The volume of lithium-ion batteries (LIBs) entering and exiting Washington's salvage, recycling, and reuse sector is increasing every year. There is active debate about when or if the EV battery reuse and repurposing market will reach saturation. The capacity of this market adds another unknown in understanding when EV batteries will need to be recycled or disposed of. If the market continues to expand, most EV batteries may have an extended life prior to being recycled or disposed. The projections of when there will be a significant volume end-of-life batteries to manage in Washington will be influenced by this market.

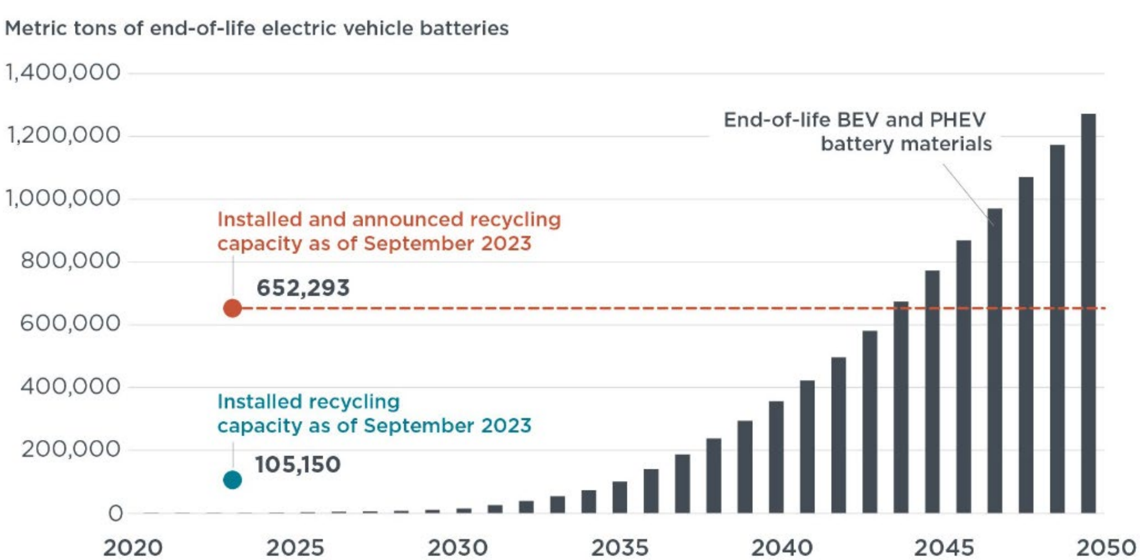

Figure 5. Recycling capacity versus projected end-of-life EV battery materials in the U.S.[18].

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[17] https://www.b2uco.com/technology.

[18] https://theicct.org/us-ev-battery-recycling-end-of-life-batteries-sept23/.

Knowledge gaps

- What is the estimated volume of EV batteries currently being collected in Washington?
- What is the ten-year projection for EV batteries requiring end-of-life management?
- What is the number of EV batteries reaching end-of-life due to vehicle incidents?
- What volume of EV batteries have a second and third life in Washington state?
- How long do second and third lives for EV batteries typically last?
- What is the capacity of the reuse and repurposing market in Washington state?

Regulations

This section of the literature review provides information on current regulations that apply to end-of-life EV batteries and related processes. The storage, management, and transportation of EV batteries in Washington is controlled by a system of state and federal laws. State and federal regulatory mechanisms are summarized, highlighting some challenges with the current management system. Existing knowledge gaps are covered at the end of the section. This section is guided by the following question, as directed by Ecology.

- What regulations govern the collection, transportation, storage, processing, and recycling of EV batteries in Washington state?

Key takeaways

- EV batteries are regulated by a combination of state and federal transportation, fire, and waste codes.
- An EV battery removed from the original vehicle in Washington is classified as either a "product" if undamaged or reusable, or a "waste" if the battery is damaged or unusable for its intended purpose.
- Damaged batteries are regulated in Washington as dangerous waste. Washington's current regulation of batteries as dangerous waste is more stringent than the federal code and highlights the need for a nationwide set of requirements for handling EV batteries across the country.

Findings to date

The State of Washington regulates the storage and disposal of batteries at their end of life through a combination of transportation, fire, and waste codes. However, the rules do not specifically, or holistically, address the end of life of lithium-ion (LIB) EV batteries and their unique characteristics. Federal regulations also address batteries as waste and include specific requirements for safe transportation.

A summary table of state and federal regulations pertaining to the management of EV batteries is provided in Appendix C. The sections below discuss the state and federal rules influencing the management of EV batteries.

Federal regulation of batteries as waste

The U.S. Environmental Protection Agency (EPA) considers batteries to be a universal waste, as defined in 40 C.F.R. part 273. The agency determined that most lithium-ion batteries on the market today are likely to be hazardous waste when they are disposed of due to their ignitability and reactivity characteristics. Although EV batteries meet the regulatory definition of hazardous waste, most businesses will manage them under a "streamlined" set of universal waste rules, unless damaged.

The U.S. EPA also states that an EV battery can be evaluated and determined to be a product, rather than waste if there is a "reasonable expectation of reuse" when evaluated by an electronic waste reverse logistics provider. The requirements for handlers of universal waste allow certain management activities, such as sorting and mixing batteries, provided that the batteries or cell casings are not breached and remain intact. The disassembly of a battery pack into individual modules or cells with no damage done to the cell casing does not make a battery damaged or defective.

Federal regulations pertaining to the transportation of batteries

Transportation of EV LIBs is regulated by the U.S. Department of Transportation (DOT) as a Class 9 ("Miscellaneous") hazardous material. The packing and shipping of LIBs must meet specific requirements. Lithium cells or batteries, including lithium cells or batteries packed with, or contained in equipment, must be packaged in a manner to prevent short circuits, damage caused by shifting or placement within the package, and accidental activation of the equipment. The shipping and packing requirements are more stringent for damaged batteries than those that are still functional. Auto sellers, scrap processors, dismantlers, and disassemblers are responsible for ensuring that the transportation and shipping of EV batteries follows DOT regulations.

Transportation of used or scrap vehicles

The Washington Vehicle Code requires any entity handling or transporting used or scrap vehicles to comply with Title 46 of the Revised Code of Washington (RCW). Motor vehicle transporters, hulk haulers, scrap processors, and vehicle wreckers operating in Washington state must maintain a valid license.

Washington State Fire Code

The 2021 Washington State Fire Code addresses the hazards associated with the use of lithium-ion and lithium-metal batteries. Retired batteries must be stored in compliance with the Washington state fire codes. New code language adopted from the 2024 International Fire Code (IFC), assists in regulating the storage of LIBs. The codes include guidelines for permitting, fire safety plans, indoor and outdoor storage, construction requirements, fire protection systems, explosion control, and reduced requirements for the storage of partially charged batteries. In addition, the National Fire Protection Association provides standards that define the requirements for operation, maintenance, and decommissioning of stationary energy storage systems, which are a possible post-first life application of EV batteries.

Washington State waste regulations

The WA Dept of Ecology regulates dangerous waste under WAC 173.303. Most batteries meet the definition of dangerous waste but are also included in the definition of universal waste. These regulations do not address EV batteries specifically but are covered under the current regulations as a general battery. Washington's definition of dangerous waste is more expansive than the federal designation of hazardous waste.

Current state regulations apply to the contents of a battery, but not the state of charge. An EV battery removed from the original vehicle could be classified as either a "product" if undamaged or reusable, or a "waste" if the battery is damaged or unusable for its intended purpose (the storage and discharge of energy). Batteries categorized as waste are regulated as "spent material."

Waste generators are required to evaluate a LIB to determine whether it meets the criteria and qualifies as dangerous waste or universal waste. Businesses may manage spent EV LIBs as a universal waste unless damaged.[19] Strict storage time limits, disposal, and shipping requirements apply to management of batteries designated as dangerous waste.

Insights into the application of Washington State regulations and codes

Interviews, survey results, and webinars with EV battery stakeholders suggest that training is needed to clarify and provide guidance on Washington State's dangerous waste regulations. Confusion exists on how to identify a damaged EV battery and how to comply with U.S. DOT shipping regulations. Stakeholders also emphasized the need for guidance, resources, and funding to train first responders on EV battery assessment, collection, transport, and disposal at the scene of an accident or following an incident (fire, flood, etc.).

Knowledge gaps

- How can damage to end-of-life EV batteries be assessed to classify a given EV battery as 'waste' or a 'product'?
- What are the characteristics that indicate that a battery is no longer able to serve its intended purpose and is therefore designated as waste?
- To what degree do the existing regulations impact the feasibility of the reuse, repurposing, and recycling of EV batteries? This will be a key area of investigation during stage two of the project.
- How might the existing regulations prevent or promote the abandonment of an EOL EV LIB?
- How might battery chemistry research influence the demand for revised policies that redefine a 'battery' and specify regulations and guidelines unique to specific battery chemistries?

[19] WAC 173-303-573.

Common post first life applications and end of life pathways

This section of the literature review provides preliminary findings on the current management of EV batteries reaching end-of-life in Washington state, as well as applications for post first life EV batteries. Factors that contribute to these end-of-life pathways are also discussed. Existing knowledge gaps are covered at the end of the section. This section is guided by the following questions, as directed by Ecology.

- What second-life use-cases exist for EV batteries?
- What are the common pathways for EV batteries at their end-of-life?
- What happens to EV batteries after they are collected?
- Where are EV batteries stored or stockpiled once they are removed from vehicles?
- At what facilities might storage occur?

Key takeaways

- There are two major pathways for EV batteries at their end-of-life which are determined by whether the battery is managed by the OEM network and what initiates the end-of-life.
- The majority of EV batteries are currently under warranty and OEMs are responsible for their proper recycling, reuse, and repurposing.
- The demand for EV battery reuse and repurposing exceeds supply, which means that a strong market exists for EV batteries that are out of warranty and EVs that are damaged through collision, flood, fire, and other incidents.
- EV batteries cannot be removed easily by non-skilled labor or abandoned easily due to their size and weight.
- Maintaining economic viability for the auto recycling industry is important because safe dismantling of ICE vehicles and their hazardous components or materials at end of life needs to continue for decades. This industry can serve an important role as EVs reach end of life in larger numbers in Washington state.
- Changes in policies, regulations, battery chemistry mix, cost of transportation, cost of recycling, and market value of critical minerals at any time could create a situation where EV batteries reach a negative value. Abandonment could become more common.

Findings to date

As the State of Washington begins to have more EV batteries reaching the end of their first life, multiple entities are involved in moving batteries into their next life cycle stage. According to the National Renewable Energy Laboratory, a new EV battery's life cycle is 12 to 15 years. The same battery's reuse lifetime ranges from five to 30 years depending on how it is used.[20] This section first describes common pathways for EV batteries at their end-of-life, which includes information on the second-life use cases and what happens once EV batteries are collected. Following the pathways discussion there is a discussion of transportation and storage, which affect all pathways.

Pathways

Many factors determine the future of used EV batteries within and beyond Washington state**.** This report defines two major pathways that are defined by who manages the battery, the dealership and vehicle OEM network or the vehicle or battery owner. There are four broad categories of events that initiate an EV battery's entry into the two major pathways, which are described below. After discussing each path and the entry ways to these paths, battery cessation is discussed. For the purposes of this report battery cessation is defined as when recycling, disposal, or abandonment cause an end to a battery's pathway.

- Pathway 1: Dealership and OEM Network
    - Battery under warranty
    - Recall
    - Battery out of warranty

[20] Kelleher Environmental, Gracestone Inc, & Millette Environmental. (2019). Research study on reuse and recycling of batteries employed in electric vehicles: The technical, environmental, economic, energy, and cost implications of reusing and recycling EV batteries. September 2019. https://www.api.org/~/media/files/oil-and-natural-gas/fuels/kelleher%20final%20ev%20battery%20reuse%20and%20recycling%20report%20to%20api%2018sept2019%20edits%2018dec2019.pdf.

Pathway 2: Outside of Dealership and OEM Network

- Vehicle incident
- Battery out of warranty

Battery cessation: Recycling, disposal, and abandonment

The two paths share steps, split, and converge (Figure 8). The information presented here is a simplification and differences exist between OEMs. A battery that is out of warranty can enter either of the major pathways. Finally, this report focuses on battery management in WA and the U.S. Export is an exit from the major pathways and is not considered part of battery cessation.

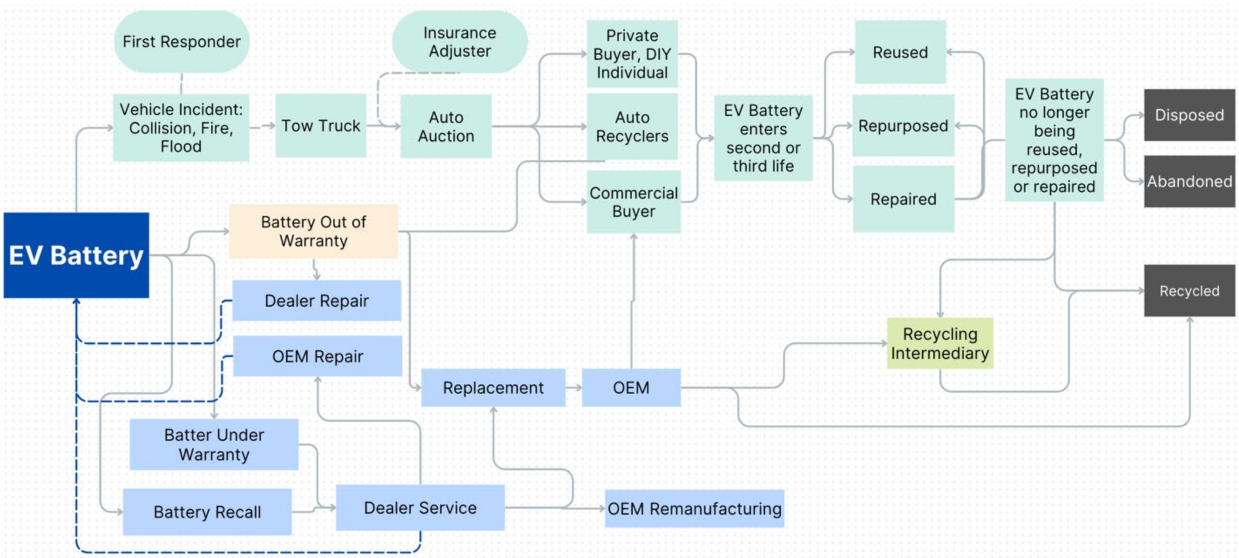


Figure 6. Overview of potential end of life pathways for EV batteries.

Pathway 1. Dealership and OEM network

Vehicle manufacturers are responsible for EV batteries. Warranty regulations and programs require vehicle manufacturers to properly reuse, repurpose, or recycle an end-of-life EV battery that is under warranty and removed from a car. In some instances, the dealership or OEM network will accept out-of-warranty batteries.

OEM warranty and redeployment of used LIBs

Federal regulation in the U.S. mandates that electric car batteries be covered by warranty for a minimum of eight years and 100,000 miles. “Some automakers only cover (warranty) an EV’s battery pack against a complete failure, while automakers like Tesla, Nissan and Volkswagen will honor the warranty if the capacity percentage drops below a specified threshold, typically 60-70 percent, during the warranty period.”[21] The benchmark for state of health (SOH)

[21] Nicholas, D. (2023.) EV battery warranties and exclusions. GreenCars. June 2023. https://www.greencars.com/greencars-101/ev-battery-warranties-and-exclusions#:~:text=EV%20Battery%20Warranties%3A%20Manufacturer%20Coverage,a%20minimum%20of%20eight%20years.

proposed by the California Air Resources Board is 80% when compared to the battery's original capacity. These warrantied batteries generally returned to the OEM via a dealership or service center

When an EV comes to a dealership or OEM service center and the battery is under warranty, some of these entities are able to repair the battery. When the EV battery is not repaired, the battery is generally replaced with a new battery. Auto dealers work closely with their respective OEMs to return EV batteries if there is an issue with the battery that requires it to be removed. Batteries spend minimal time at an OEM service center or dealership before transport to the OEM prior to the next stage of life. Some dealerships wait to remove a battery from a vehicle until the replacement arrives from the OEM.

When the EV battery is returned to the OEM, it may be remanufactured, recycled, or sold where it may enter second-life use cases. Remanufacturing is when entities replace EV battery parts, such as modules or cells, and the battery can re-enter vehicles. These processes may be carried out by another company.

Spiers New Technologies, remanufactures, repurposes, and recycles battery packs for approximately 65% of the non-Tesla OEMs including Ford, GM, Nissan, Porsche, Toyota, VW, and Volvo. "As many as 2,000 battery packs are shipped monthly into the company's Oklahoma City facility, where they are assessed and rehabilitated or put to a new purpose." Additional facilities exist in Los Angeles and Detroit, but not Washington State. According to the owner, Dirk Spiers, "Eighty- to ninety percent can be refurbished and returned to a vehicle, 5-10% will be recycled, and the remaining batteries [are] repurposed."[22] These percentages may vary depending on each manufacturer's procedures and practices for rehabilitation.

Recalls by OEMs

Recurrent Auto estimates an EV battery failure rate is approximately 1.5%. Recalled batteries are returned to the OEM for repair or recycling.

Out of warranty repairs and service by dealers, OEMs

The majority of EV batteries currently in cars are under warranty. Dealers may service a battery in an out-of-warranty vehicle. While this is not a major pathway, the number of out-of-warranty batteries will increase over time. Tesla has the largest population of out-of-warranty vehicles and offers replacement batteries for owners who are not satisfied with an out-of-warranty vehicle's range. When an EV battery is out-of-warranty, the owner generally must pay out of pocket for a battery replacement.

Pathway 2. Outside the original equipment manufacturer (OEM) network

An EV battery that is outside the OEM network can take many paths. These batteries exit the OEM network when there is a vehicle incident, and the battery is out of warranty.

[22] *Where do EV batteries go when they die?* https://www.youtube.com/watch?v=HIurjZsWJoc.

Vehicle incidents resulting in auto auction

EV batteries enter the marketplace when there has been an incident such as a collision, flood damage, fire damage, or other events triggering insurance claims. Initial interviews suggest that the EV battery is often undamaged, and the health of the battery determines its value. The value of the battery is a major determinant of the path it takes.

In the event of a collision, a vehicle's ownership is often transferred to an insurance company and resold via insurance auctions across the country. These damaged vehicles are purchased by a wide array of buyers including auto recyclers, commercial businesses built around consumer or fleet EV conversions, repurposing businesses creating grid storage solutions, and a large DIY community. In rare but documented instances, buyers remove good batteries from vehicles and replace them with an inferior battery before resale of the vehicle at auction.

Auction purchases may arrive in Washington from across the United States, shipped to the buyer for around $1,000-2,000. Washington EVs sold at auctions may also leave the state and be dispersed across the U.S. The number of batteries entering and leaving the state through auctions is unknown. Auctions may also be a means through which EVs and the batteries in them are exported out of the U.S.

Auto recycling companies, also referred to as dismantlers and salvage yards, commonly purchase EVs from insurance auctions. These vehicles are transported to the auto recycling facility which dismantles the vehicle to resell the parts of value before crushing and selling the vehicle shell for scrap after the dismantling process is complete.

Dismantlers purchase damaged EVs when the price point allows for a slight profit from the recollection, removal, and resale of a used EV battery and other EV parts. The EV battery is the most valuable part of the EV due to current economic conditions. Unless the whole vehicle is being resold, batteries are often removed from an EV for resale. EV batteries often weigh around 1,000 pounds or more for large batteries in pickups and SUVs. An automotive lift is required to remove a battery. Special training and tools help keep workers safe as they remove the battery. Learning to safely work on high voltage systems (400 and 800 volts) may be a new skill for some auto recyclers.

Interviewees stated that it is common for auto recyclers in Washington to immediately isolate a battery if it is determined to be damaged. Often a third-party carrier will come to the facility to package and transport a battery to an appropriate recycler. Auto recyclers shared that this process is expensive.

A number of stakeholders shared that it is important to maintain economic viability of auto recyclers as the market transitions to EVs. Auto recyclers currently support the safe dismantling of vehicles with internal combustion engines (ICE vehicles). They will have an important role when more EVs reach end-of-life in Washington state.

With a wide range of buyers, EV batteries are dispersed into multiple marketplaces for reuse and repurposing. Types of repurposing include energy storage systems supplying backup power for renewable energy generation and back-up storage for buildings, DIY repurposing for home backup power, RVs, boats, or other applications. A number of individuals and entities in Washington are converting ICE vehicles to electric vehicles, while B2U Storage Solutions is using repurposed Nissan LEAF batteries to store energy collected from its 1 MW solar farm located in Lancaster, California.

The demand for EV batteries for reuse or repurposing exceeds the supply, which means that the value of the battery exceeds the cost of transportation. A twelve-year-old Tesla Model S 85kWh battery may sell for $15,000 to $25,000 in an auction, according to interviews and online auction sites. This same 1,200-pound battery may sell to a battery recycler for only $240 to $1,200, because recyclers only pay for the value of the battery's materials, not its function of storing and discharging energy. While no publicly accessible data exists for the composition of buyers, it seems likely that not many batteries are currently reaching recycling through this pathway based on the economics.

The market dynamics are unlikely to shift until there is a larger volume of end-of-life batteries to increase supply. There are different perspectives on the potential size of the reuse and repurposing industry. Some believe that it will saturate and that end-of-life batteries will be recycled rather than having a second life, while others think that the second-life use-cases will continue to grow.

Out of warranty batteries or non-insured batteries

When EV batteries are out of warranty, independent repair shops or individuals engaged in DIY repair may service them after diagnostic testing. In cases where the battery is not repaired for use in its original vehicle, the batteries may be sold to private or commercial businesses for reuse or repurposing.

Battery cessation: recycling, disposal, or abandonment

Battery cessation occurs when an EV battery exits or bypasses second- or third- life. When this happens, a battery may be recycled, disposed of, or abandoned.

Approximately 98% of critical minerals in EV batteries are recoverable through recycling. Recycling centers are being built around North American to support the battery supply chain and vehicle manufacturing. In certain cases, OEMs have relationships with recyclers or recycling intermediaries that allow them to manage EV batteries for which they are responsible. A discussion of the economic drivers and incentives is included under the economics section of this report.

Initial stakeholder interviews suggest that abandonment and disposal of EV batteries are not major mechanisms for battery cessation. This is due to the high value of second-life batteries and the fact that most EV batteries are still under warranty.

The lack of knowledge regarding where to send batteries and/or the perception that handling costs are too high may result in the disposal or abandonment of EV batteries. Smaller organizations outside OEM networks may not always know which organizations to work with to properly recycle EV batteries in a cost-efficient way. Increasing the awareness of networks and solutions for stranded batteries could support smaller operators. Changes in policies, regulations, battery chemistry mix, cost of transportation, cost of recycling, and market value of critical minerals at any time could create a situation where EV batteries reach a negative value. If EV batteries reach a negative value, then abandonment could become more common.

Considerations for all pathways

Transportation

Transportation can make up roughly half of all recycling costs. Transportation methods of EVs and EV batteries vary depending on the pathway and even within pathways. OEMs may employ their own specific battery transportation procedures and processes while following the same regulations. Transportation costs will continue to be a driver of determining what happens to an EV battery, and changes in transportation regulation have the potential to increase or decrease the number of batteries being reused, recycled, or repurposed.

The transportation of EV batteries in the U.S. is regulated at the federal level. Stakeholders stressed the importance of a nationwide solution that helps address the high cost of transportation. The number of batteries with the potential to become stranded will be dependent on future technology developments and the commodities market.

At the state level, some jurisdictions are considering ways to allow collection sites to facilitate transportation, infrastructure development, and strategies to reduce the cost of transporting batteries. If successful, these efforts will increase the number of batteries being reused, repurposed, or recycled.

Storage considerations

The method of storage of undamaged batteries after they have been removed from vehicles depends on the entity removing the battery and which pathway the battery is following. Batteries may be removed from an EV by a dismantler, exporter, EV conversion business or individual, auto repair shop, rebuilder, scrapper, or others in the state of Washington. Initial stakeholder engagement suggests that focusing on long-term infrastructure needs and building knowledge of existing networks for recycling, reuse, and repurposing will reduce the likelihood of batteries being stockpiled or stored for extended periods of time.

If batteries are damaged more stringent regulations apply to their storage as well as transportation. These batteries have the potential to burden auto recyclers. First responders may have to manage damaged EV batteries when responding to an incident and there is broad interest in supporting them with training.

Knowledge gaps

- What methods do auto recyclers use to detect damage?
- Is there a common set of best practices for damage detection?
- Do best practices exist for handling high voltage systems in EVs while dismantling them?
- If there is a set of common best practices for handling damaged batteries? Does this extend to facilities of different scales?
- What policies, training, and education can support first responders in Washington state?
- What battery information and diagnostic instruments do first responders need at the scene of a vehicular accident to assess if a battery is damaged, if special precautions are needed, and where the vehicle should be towed?

- What is needed to improve workforce safety of EV LIB handlers?
- How can the number of salvaged EVs and batteries from auto auctions be tracked to project the future volumes of batteries reaching ultimate end-of-life and recycling?
- What tools can be used to provide EV battery sellers, buyers, reusers, repurposers, and recyclers access to battery information?
- What market conditions will drive the stockpiling and abandonment of out of warranty LIBs?

Economics of battery management

This section of the literature review provides preliminary findings on the economics of EV battery management in Washington state. Factors that contribute to these economic considerations are also discussed. Understanding the economic dynamics of recycling LIBs is critical, with profitability influenced by factors such as transport costs, battery chemistry, and recycling methods. Additionally, the challenges associated with the increasing volume of end-of-life LIBs highlight the importance of efficient collection networks, financial responsibility frameworks, and state and federal incentives. Existing knowledge gaps are covered at the end of the section. This section is guided by the following questions, as directed by Ecology.

- What is the financial landscape surrounding EV batteries?
- Are there existing programs that provide funding or incentives for EV battery management?

Key takeaways

- The value of an EV battery changes over time, depending on its condition and the market value of its materials. EV batteries with over 70% capacity have the highest resale value.
- Battery production costs are decreasing due to economies of scale.
- Recycling LIBs can be economically viable – profitability depends on factors like transport costs, battery chemistry, pack design, and recycling methods.
- Collection and transportation costs vary based on whether the battery is damaged, distance to a recycling facility, and the volume of batteries shipped.
- OEMs and vehicle owners are the main responsible parties for proper EV battery disposal, depending on the warranty status of the battery.
- Cost and logistical barriers to EV battery management in Washington state are high in part because much of the domestic battery industry is located in the southern U.S.
- There are several existing financial incentive programs related to the Inflation Reduction Act and Infrastructure Investment and Jobs Act that can support industries involved in end-of-life EV battery use and management to reduce the costs of battery disposal.

Findings to date

The value of an electric vehicle (EV) battery changes over time, depending on factors like its condition and the market value of its materials. These materials, ranked by value, include cobalt, nickel, copper, and lithium. When reselling, EV batteries with over 70% capacity have the highest value. Table 1 summarizes the value of new or nearly new EV batteries.

Table 1. EV battery replacement costs.

Battery Type	Battery Capacity	New/Like New Battery	$/kWh	Data Source:
Tesla S	100 kWh	$12,000-$15,000[1]	$153	Find My Electric
Tesla 3	75 kWh	$13,500	$137	J.D. Power, Recurrent Auto
Chevy Bolt	66 kWh	$16,000	$250	Recurrent Auto
Nissan Leaf	40 kWh	$4,500	$187	Recurrent Auto

1. Estimate https://www.findmyelectric.com/blog/tesla-battery-replacement-cost-explained/

Battery production costs are decreasing, with the average price dropping from $137/kWh in December 2020 to a projected $62/kWh by 2030.[23] This reduction is due to economies of scale, and further decreases may require technological advancements like solid-state batteries.

The second-life use of batteries is a growing industry, driven by demand for EV conversions and stationary energy storage. Auto recyclers face competition at auctions, especially in Washington where active EV associations, like the Seattle EV Association, contribute to innovation. There's potential for economic benefits in repurposing batteries for non-automotive uses, such as energy storage. Collaboration with research institutions and business incentives may promote innovative technology and commercial ventures, extending the life of batteries and managing recycling costs.

It is important to note that there are different pricing metrics for EV batteries depending on industry segment. Currently, the common metrics employed are $/kWh and $/pound. Through much of an EV battery's life, from production to post first life, it is priced in $/kWh according to its energy capacity. However, recyclers often pay for EOL batteries in $/pound. It is possible to convert between these two values if the battery's energy density is known.

Recycling lithium-ion batteries (LIBs)

Research suggests that recycling LIBs can be economically viable, with costs ranging from -21.43 to +21.91 $/kWh.[24] Profitability depends on factors like transport costs, wages, battery chemistry, pack design, and recycling method. Recycling of EV batteries in the U.S. is expected to be profitable at around 7–8000 tons per year.[25]

[23] https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

[24] "Financial viability of electric vehicle lithium-ion battery recycling", Lander et al, iScience Volume 24, Issue 7, 23 July 2021, 102787

[25] https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

Without appropriate networks and solutions, EV batteries may end up stranded. Changes in policies, regulations, battery chemistry, transport costs, recycling costs, and market value of minerals could lead to situations where EV batteries have a negative recycling value.

Transporting lithium-ion batteries (LIBs)

The volume of LIBs entering and exiting Washington's reuse, salvage, and recycling sectors increases every year. The costs associated with recycling include the collection and transportation of the battery, dismantling and disassembly, and the recycling process itself.[26] Collection and transportation costs vary based on whether the battery is damaged, distance to a recycling facility, and the volume of batteries shipped.

Transporting individual batteries to a recycling center can be an intensive cost component if higher volumes of batteries cannot be consolidated and shipped at the same time to increase cost efficiency. Additional costs are associated with transporting damaged batteries because they have an increased risk of fire and, as a result, require extra precautions to ship. This includes additional packaging that must be custom-made and comply with U.S. DOT standards.

Shipping costs can be decreased with an efficiently designed collection network that optimizes collection points and existing infrastructure, such as dismantlers and dealerships. Because of their access to vehicles coming off warranty, manufacturers are in a prime position to lead this centralized planning and ensure that operations are in place for all batteries to be recycled, which would likely lead to economic benefits from economies of scale.

Financial responsibility

The Original Equipment Manufacturer (OEM) is generally responsible for end-of-life recycling if the battery pack is under warranty. For out-of-warranty batteries, vehicle owners typically bear the costs of disposal. Many stakeholders support a national solution, with some suggesting a system of Extended Producer Responsibility (EPR) to alert OEMs about battery issues throughout end-of-life to prevent stranded batteries. Some states, like California, have explored core exchange programs. See the Other Jurisdictions section for more details. These potential solutions will be discussed further in the final legislative report.

Private partnerships

As Washington's EV footprint expands, the process of shipping used LIBs out-of-state will increase in cost and become more logistically challenging given interstate transportation regulations and the sheer number of batteries being shipped in the future. At the moment, much of EV battery manufacturing and recycling is done in the so-called "battery belt" across the South. Therefore, the Washington state EV and EV battery system is geographically removed from many battery manufacturing and assembly firms, as well as remanufacturing, refurbishment, recycling, and related aftermarket industries. This exacerbates the cost and logistical barriers of reusing and recycling EV batteries in Washington state.

Considerations for addressing this issue may include incentivizing efficient recycling hubs and other private partnerships in the EV battery industry. Attracting these firms to the region could

[26] Electric vehicle lithium-ion battery recycled content standards for the US – targets, costs, and environmental impacts; Dunn et all, Resources, Conservation and Recycling Volume 185, October 2022, 106488, October 2022.

reduce transportation challenges and support the regional economy. At the same time, discussions about creating regional infrastructure will need to take into consideration possible community and environmental impacts of future EV battery-related industrial activities in the region. These concerns will need to be factored into the overall economic benefits analysis.

Cost share opportunities and initiatives

The anticipated growth in the number of EVs operating in Washington has the potential for both positive and negative economic impacts, some of which could be substantial.

Local businesses centered around internal combustion and hybrid vehicle service, maintenance, and repair already exist in limited numbers. However, businesses focused on servicing EVs are limited. As the need grows to support out-of-warranty EVs, it is anticipated that the demand for such services in Washington state will grow substantially. These businesses will eventually create jobs, enhance the tax base, and support local economies.

Various forms of support will likely be needed to ensure the long-term viability of this industry segment, including access to vocational training around battery service, clear communication from state and local authorities concerning battery end of life processes, as well as the potential for start-up funding for new ventures in underserved communities or in parts of the state where EV penetration is currently low but anticipated to rise. Many incentive mechanisms may support this growth including grants and low-interest EV business incentive loans.

State initiatives and federal funding opportunities

There are a number of applicable statewide initiatives that support the growth of the battery industry through the transportation and electricity sectors, in addition to promoting environmentally responsible battery disposal. To the point of this study, SB 5144[27] directs the Department of Ecology to review pertinent issues for managing electric vehicle batteries by Nov. 30, 2023. Other mandates include the state's initiative to increase purchases of environmentally preferable products, reduce greenhouse gas emissions, and reduce energy use.

There are several existing financial incentive programs that can support industries involved in end-of-life EV battery use and management to reduce the costs of battery disposal. Applicable incentives are primarily through the Inflation Reduction Act (IRA) and Infrastructure Investment and Jobs Act (IJA). Regardless of their origin, battery materials recovered in domestic recycling and are used in a qualified project count as "domestic content" in the manufacture of new batteries. The IRA provides a 30% Investment Tax Credit (ITC) for new recycling facility construction and may offer a 10% bonus for zero emissions energy projects that utilize domestic content. IRA Direct Pay enables public entities to construct facilities that may qualify for federal tax credits. The Federal Direct Pay options directly enable public entities to take on responsibility, and potential revenue, of battery recycling centers. IJA provides grants to entities constructing qualified projects. The ITC concept can also be extended through partnership with private entities to construct and operate a recycling center dedicated to meeting state mandates.

[27] SB 5144 - 2023-24 "Providing for responsible environmental management of batteries".

Knowledge gaps

- What is the profitability associated with recycling different EV battery chemistries?
- Which recycling methods appear to have the most favorable economics?
- Economically viable EV lithium-ion battery recycling is increasing. What are the routes to profitability in Washington state? What industry segments need further development?
- What are the implications, positive and negative impacts, of assigning responsibility of EV management to electric vehicle owners in Washington state?
- What barriers exist as the industry continues to establish and refine the ecosystem supporting EV battery collection, transportation, and reverse logistics in Washington state (i.e., acquisition, management, and transport of used EV batteries)?
- How might shipping and packaging regulations be modified, based on battery chemistry, to relieve the cost burden of transportation and promote an increase in recycling?
- At what price point are incentives needed to prevent the stockpiling and abandonment of EOL EV batteries?
- What market conditions drive the stockpiling and abandonment of out of warranty LIBs?

Battery chemistry and value

This section of the literature review covers battery chemistry considerations and the associated value of EV batteries currently. Remaining knowledge gaps are covered at the end of the section. This section is guided by the following question, as directed by Ecology.

- What characteristics and values are associated with the most common EV battery chemistries?

Key takeaways

- There are two main categories of lithium-ion EV battery chemistries – nickel-based chemistries and lithium iron phosphate (LFP).
- Cobalt and nickel are the two most valuable materials in lithium-ion batteries. Both of these materials are only used in nickel-based battery chemistries.
- Battery value varies over time, depending on fluctuating commodity markets for battery materials.
- Many EV batteries currently reaching end-of-life in Washington and around the country contain high amounts of cobalt and nickel.
- The rate of return for recycling lithium iron phosphate (LFP) batteries, which lack cobalt and nickel, is lower. Profitability for LFP recycling depends on a high enough price of lithium in the spot market.
- The research indicates that recycling LFP is not currently profitable, therefore creating a disincentive to eventual recycling.

- LFP batteries have much longer lives than nickel-based chemistries. This means that they may be high-value candidates for repurposing after serving their first life in an EV, such as use in stationary storage applications, and may not be ready to be recycled for 20-30 years.

Findings to date

Background

The cost of battery manufacturing is now dominated by the cost of the constituent materials. Through much of the 2010s, the cost of EV battery production was dominated by the cost to assemble the battery. This switch has happened because battery manufacturing has now realized production cost reductions from economies of scale. Therefore, much of what determines the value of an EV battery is its chemistry.

While all EV batteries contain lithium in the electrolyte, battery chemistries are categorized by their cathode material. There are two main categories of lithium-ion EV battery chemistries – nickel-based chemistries and lithium iron phosphate (LFP). Nickel-based chemistries include nickel-cobalt-aluminum oxide (NCA) and nickel-cobalt-manganese (NCM), which both contain cobalt and nickel. While LFP batteries lack both cobalt and nickel, they contain copper foils in the anode and lithium in the electrolyte. EV batteries hold value across several areas of the battery cell, including the materials within the cathode, electrolyte, and anode.

Because all EV battery chemistries contain lithium, they all rely, to some extent, on the lithium commodity market to determine their value. Commodity markets are famously volatile, and the lithium market is no exception. Lithium commodity prices experienced a 15-fold price spike during the pandemic and have since returned to 2017 levels after this spike.[28]. Cobalt, nickel, and copper market prices also fluctuate based on market dynamics.[29] [30] [31] Spot market price volatility can be exaggerated by small changes in real world conditions. For any commodity, and especially battery materials, a price spike causes a surge in investment to fill this need, which often leads to short term oversupply and price drops.

Nickel-based battery chemistries

While nickel-based chemistries contain lithium, they also contain two materials – cobalt and nickel – that are much more valuable than lithium and thus play a larger role in determining battery value. Cobalt is the costliest material used in EV batteries, which makes it most valuable for EV battery recyclers. Nickel is the second most valuable material to recyclers. Many EV batteries currently reaching end-of-life in Washington and around the country contain high amounts of cobalt and nickel.

These two minerals have been instrumental in EV success, allowing batteries to be smaller while enabling EVs to go further. However, due to high costs and environmental and societal

[28] https://tradingeconomics.com/commodity/lithium.
[29] https://tradingeconomics.com/commodity/cobalt
[30] https://tradingeconomics.com/commodity/nickel
[31] https://tradingeconomics.com/commodity/copper

concerns associated with cobalt mining, auto and battery OEMs have steadily been reducing the percentage of cobalt in their nickel-based chemistries[32 33].

Lithium iron phosphate (LFP) batteries

Because cost is a main driver of battery evolution, lithium iron phosphate (LFP) batteries – which do not contain expensive cobalt or nickel – are rapidly gaining market share for standard range vehicle offerings from most manufacturers. Additionally, LFP batteries have a lighter and simpler battery thermal management system, which greatly reduces risk of thermal runaway and fire. LFP batteries can also endure three to five times more charge/discharge cycles than nickel-based chemistries.

While they are less expensive to manufacture, the rate of return for recycling LFP batteries is lower than nickel-based chemistries because they lack valuable cobalt and nickel. Therefore, the profitability of recycling LFP batteries depends on the prices of lithium and copper in the spot market. While LFP batteries represent a miniscule fraction of batteries currently reaching end-of-life, they will eventually make up a significant proportion of end-of-life batteries. The research indicates that recycling LFP is not currently profitable, therefore creating a disincentive to eventual recycling.

Potential mechanisms to ensure that LFP batteries are not stranded at end of life because of low commodity prices may be important to consider. Fortunately, LFP batteries have far longer lives than nickel-based chemistries, so there is time to identify solutions. LFP batteries may be high-value candidates for repurposed EV batteries in stationary storage applications after serving their first life in an EV. This could translate into a 20-30+ year lag before today's new LFP batteries are ready for recycling.

Evolving battery landscape

As battery recyclers respond to the influx of different EOL batteries, they are paying attention to future battery designs and chemistries. As more EVs retire and technology changes, stakeholders will likely prioritize recycling batteries of higher material value and a shorter transportation distance to the recycling center.

Knowledge gaps

- What is the tipping point or price at which LFP batteries become economic to recycle?
- What policies or solutions may support recycling battery chemistries that do not contain valuable minerals?

[32] https://www.energy.gov/eere/vehicles/articles/reducing-reliance-cobalt-lithium-ion-batteries
[33] https://www.autonews.com/manufacturing/can-ev-battery-makers-move-away-cobalt

Other Jurisdictions

The consultant team identified relevant case studies that may inform considerations for EV battery management in Washington state. These case studies focused on California and Colorado, as both states have released reports on EV battery management in the last two years. Relevant takeaways and recommendations from each report are detailed in this section.

Key Takeaways

- Manufacturers are required to properly reuse, repurpose, recycle, and manage the EV batteries under warranty.
- Out-of-warranty batteries are difficult to track and there are discussions in other jurisdictions attempting to define who is responsible for out-of-warranty EV batteries.
- Most EV batteries are still under warranty and in their original vehicle.
- California and Colorado are discussing different infrastructure needs to build collection and transportation networks to prepare for when there is a larger volume of end-of-life EV batteries.
- California is investing in research and development around EV battery uses during second life, and Colorado's research team recommended investments in research and development. Both are incentivizing businesses associated with EV battery end-of-life management or considering investments.

California

California Environmental Protection Agency (CalEPA) identified potential policies to address the management of Li-ion EV batteries by forming the Li-ion Car Battery Recycling Advisory Group (Advisory Group). The Advisory Group spent 3 years developing policy recommendations after hearing from 26 experts representing industry, academia, and government agencies. Their findings and policy recommendations can be found in the Lithium-ion Battery Recycling Advisory Group Final Report[34].

Findings from California and policy proposals

There are existing warranty regulations and programs that require vehicle manufacturers to properly reuse, repurpose, or recycle a removed EOL battery that is under warranty. Out-of-warranty LIBs were identified as a challenge in California. There is no method to track out-of-warranty LIBs in California. As a result, the volume of out-of-warranty batteries or their locations is unclear. The authors state that "retired EVs may end up being handled by several different parties who have unequal access to the resources and information necessary to manage EOL batteries properly."

[34] https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-Recycling-Advisory-Goup-Final-Report.pdf

Two major policies were proposed by the Advisory Group to complement the existing management of EOL batteries that are under warranty: 1) core exchange with vehicle backstop, and 2) producer take-back.

The core exchange with vehicle backstop policy aims to recapture out-of-warranty LIBs using a similar process that the state uses for lead-acid batteries. A core charge is a form of deposit made when a new battery is purchased. When the battery is returned, the deposit is refunded.

The core exchange with vehicle backstop policy and producer take-back policy defines responsibility for the return of the EV battery based on two scenarios. In the first scenario, the battery reaches end-of-life before the vehicle reaches end-of-life. The entity removing the EOL battery would hold responsibility for its proper reuse, repurposing, or recycling. The entity selling an EV battery would use a core exchange program to track that the used battery was properly managed.

In the second scenario, the EV reaches end-of-life before the EV battery and goes to a dismantler. The dismantler who has ownership of the end-of-life vehicle has responsibility for the EV battery and is responsible for ensuring the battery is properly reused, repurposed, refurbished, or recycled. If the battery goes to a separate entity for refurbishing or repurposing, the responsibility goes to the new entity.

The proposed producer take-back policy applies to situations where an EV reaches end-of-life and doesn’t go to a dismantler. In this case, the vehicle manufacturer is responsible for the proper management of the vehicle and the battery.

Defining ownership responsibility for EV EOL management was suggested to create environmental responsibility across the lifespan of an EV battery. Additional policy needs related to the EV battery management regulatory landscape include:

- Reducing transportation costs.
- Supporting transportation research.
- Developing strategic collection and sorting infrastructure.
- Clarifying the existing universal waste regulations.
- Accessing battery information, including chemistry and OEM.

Considerations for Washington state

There are important differences between Washington state and California. The California Energy Commission (CEC), a state agency, is funding efforts to repurpose used EV batteries into grid storage. Grid stability is a major challenge in California. There is a pressing need to add more stationary storage to the grid that can be provided with the addition of repurposed batteries. As a result, California has several facilities and demonstration sites that use repurposed EV batteries for grid storage.

California has strict laws regarding vehicle dismantling and seeks to penalize dismantling outside of the state regulated system. Some stakeholders in Washington are concerned that California’s approach applied in Washington would stifle innovation in the nascent reuse and repurposing industry. The policy options generated by the California Advisory Board reflect the composition of its membership. Washington state may want to consider different policy options as input is gathered from priority stakeholders.

Colorado

In 2020, Colorado State University was tasked with reporting the status of EV battery recycling and reuse in Colorado by the Colorado Department of Public Health and Environment. Researchers analyzed the environmental, economic, and human health impacts associated with EV battery recycling and end-of-life. Stakeholder interviews and a review of the scientific and trade literature yielded insights into potential technological, regulatory, commercial, and educational initiatives that can prepare Colorado for the growth in electrified transportation. A major recommendation from the report was to form a study team to develop in-depth policy recommendations and strategies. Findings and policy options from this process can be found in the Colorado EV Battery Recycling Study[35].

Findings from Colorado and policy proposals

The researchers from Colorado found that most Li-ion batteries in the state are under warranty and in their original vehicle. The researchers did not find evidence of storage or stockpiling in Colorado. Disposal, remanufacturing, recycling, materials recovery, and second-life activities were found to be occurring out of Colorado, or at small or non-commercial scales within the state. Similar to findings in California, the researchers found that there were knowledge gaps for what happens to out-of-warranty batteries.

The researchers suggest options for value-adding initiatives that may support the new EV post first life energy economy. Recommendations include:

- Fund businesses that support second life use, recycling, logistics of EV batteries in state through investment credits and grants for EV battery research and development.
- Encourage utilities to invest in and use passive energy storage systems.
- Develop a recycling hub to create efficient and cost-effective management and distribution in the state. A recycling hub would simplify transportation and reduce its costs.
- Establish collection centers similar to what exists for the electronics industry.
- Clarify and harmonize regulations for handling, processing, disposal, and transportation of batteries.
- Resolve battery ownership in scenarios when it is unclear to reduce potential harm to the environment.
- Promote transparency and standardization for battery recycling and automotive recyclers and dismantlers.

[35] Colorado State University. (2021). Colorado EV battery recycling study. https://www.researchgate.net/publication/354131908_Final_report_Colorado_EV_battery_recycling_study.

- Create a statewide education program for sharing basic knowledge and facts about battery safety, management, and end-of-life scenarios.
- Promote consumer engagement through battery rebates, returnable deposits, recycling stipends.
- Develop an exchange program for out-of-warranty batteries to encourage consumers to return their EOL batteries for new or refurbished EV batteries to increase the number of EOL batteries that have a second life.

Considerations for Washington state

The findings from Colorado reinforce what was reported in California. Both reports emphasize the need for investing in infrastructure to collect and transport EV batteries efficiently. Neither state has a way to effectively track out-of-warranty batteries or batteries going to second- and third life. Future research and policy development from these two states and others may provide additional insights and ideas for Washington to consider.

Emerging Themes

The emerging themes discussed in this section were developed based on a literature review of EV battery management, stakeholder interviews, initial survey responses, and webinar discussions. They may change or include new ideas as additional stakeholder engagement takes place in the coming months.

- The battery industry and regulatory landscape are co-evolving rapidly.
- Industry stakeholders are refining procedures to meet federal and state regulations.
- EV battery recycling is a nascent industry undergoing rapid change.
- Training related to best practices for EV battery incident response would support first responders.
- Varying perspectives exist regarding responsibility for end-of-life batteries.
- Access to new information would support the collection, management, and safety of end-of-life batteries.
- Industry stakeholders are concerned that state-by-state regulations could create a patchwork of rules and codes that make recycling, reuse, and repurposing difficult or economically impractical.

There are mixed levels of agreement with the statement “an active market exists for batteries to be reused” due to the different perspectives on the DIY reuse community. A representative from the DIY community strongly supported the right to repair in a webinar discussing emerging themes and priorities. The DIY community member shared that the right to repair should extend to EV battery repair and reuse. Industry stakeholders expressed a preference that trained individuals manage EV battery repair and reuse due to safety concerns.

The emerging themes can be viewed as considerations for policy makers. Engagement efforts continue, and as additional stakeholder groups provide input, it is likely that these themes will change. Additional stakeholder engagement will further inform thoughtful policy and regulation, and identify emerging themes that may be missing, particularly regarding community, environmental, and environmental justice interests. Careful consideration should be given to what actions are needed at both the federal and state levels given the rapid evolution in the industry.

Appendix A. Key Definitions

Unless context indicates otherwise, the following terms have the meanings given below when used in this report.

Anode

A negative or reducing electrode[36] in a battery that releases electrons to the external circuit and oxidizes during the electrochemical reaction. For our common understanding, we can picture the negative terminal of a battery.

Auto recyclers/dismantlers

Companies that dismantle and recycle vehicles.

Battery cell

EV battery cells are the individual, basic units of a battery. Each cell functions to chemically store energy. A battery cell contains three major components, a cathode, anode, and electrolyte. The cell houses its components and electrochemical reaction within a casing. Cells may come in cylindrical, pouch or prismatic form factors.

Battery cessation

The end of a battery's lifespan resulting in disposal, recycling, or abandonment.

Battery chemistry

The battery's active materials or more specifically the materials used in the cathode, anode, and electrolyte. Shorthand generally refers to the battery's cathode materials. It is common to refer to LFP, NMC and NCA as the three most common EV battery chemistries.

Battery module

A unit that consists of a number of EV battery cells which are connected in series or parallel, forming units that produce the required voltage and energy capacity.

Battery pack

The complete enclosure that delivers power to an EV. It houses the collection of modules and cells. Modules are assembled into EV battery packs, also in series or parallel within a hard enclosure. They also contain other vital components, including software for monitoring (battery management system/ BMS) the pack and its thermal management.

[36]https://depts.washington.edu/matseed/batteries/MSE/components.html#:~:text=The%20Anode%20is%20the%20negative,reduced%20during%20the%20electrochemical%20reaction.

Cathode

The positive or oxidizing electrode[37] in a battery that acquires electrons from the external circuit and is reduced during the electrochemical reaction. Also known as the positive terminal of a battery.

Electric vehicle (EV)

An EV 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[38]. An EV includes both a vehicle that can only be powered by an electric motor that draws electricity from a battery (all-electric vehicle) and a vehicle that can be powered by an electric motor that draws electricity from a battery and by an internal combustion engine (plug-in hybrid electric vehicle- PHEV). For the purposes of this report, 'vehicle' is limited to means of transportation on roads.

End-of-life (EOL)

The moment where a battery reaches the end of its usefulness and/or lifespan, as originally manufactured, in an EV.

Energy density

The amount of energy a battery contains compared to its weight or size.

Electrolyte

The battery component which allows ions (charge carrying particles) to pass easily between the anode and cathode. Liquid electrolytes in current EV batteries are lithium salts (lithium ions).

Kilowatt-hour (kWh)

Measure of a battery's energy capacity. 1 kWh is defined as the energy consumed at a power level of 1 kW for one hour. It is also the unit used to measure electricity consumed on an electric meter. WA utility rates vary from $0.03-0.15 /kWh, averaging 13 cents/kWh in September 2023, according to the Energy Information Administration.

Lithium-ion battery (LIB)

A type of rechargeable battery which uses the reversible reduction of lithium ions to store energy.

Lithium iron phosphate (LFP)

A chemical compound, $LiFePO_4$, commonly called LFP. LFP batteries use lithium iron phosphate as the cathode material to store lithium ions. LFP batteries typically use graphite as the anode material. The chemical makeup of LFP batteries gives them a high current rating, good thermal stability, and a long lifecycle.

[37] https://depts.washington.edu/matseed/batteries/MSE/components.html#:~:text=The%20Anode%20is%20the%20negative,reduced%20during%20the%20electrochemical%20reaction.

[38] https://afdc.energy.gov/laws/12660#:~:text=An%20EV%20is%20defined%20as,charged%20from%20an%20external%20source.

Lithium nickel-cobalt-aluminum oxide (NCA)

A highly thermally stable cathode material used in lithium-ion batteries.

Nickel-manganese-cobalt (NCM)

A cathode material used in batteries. While NCM is technically LNCMO, it is called NCM for convenience's sake and is created when nickel (Ni) and manganese (Mn) are mixed into lithium cobalt oxide (LCO). Depending on the percentage of these materials in the battery's cathode, different characteristics are achieved. NCM-811 refers to the nickel-rich layered cathode material, comprising 80% nickel, 10% cobalt and 10% manganese.

Post first life application

The use of an EOL battery which helps to extend its usable life before it is ultimately recycled or disposed of. Applications include:

- Reuse in another electric vehicle after the battery has been removed from the original vehicle.
- Reuse in electric vehicles after operators create a new battery from the packs and cells that have sufficient remaining capacity through a process known as refurbishment or remanufacturing.[39]
- Reuse in an EV conversion using previously used battery modules or battery pack(s).
- Repurposing an EV battery in an energy storage system.

Remanufacturing (Refurbishing)

A process of extensive refurbishing of used, but usually not defective, products to restore them to the quality standards of the product as if it were new. To this end, the product in most cases is partially or completely disassembled in order to inspect the components and/or sub-assemblies.

Repair

A process in which a battery is serviced.

Reuse

A process in which an EV battery is used in another EV after it is removed from the original vehicle.

Repurpose

Use of EV batteries in a non-EV context, i.e., batteries used for energy storage systems.

[39] https://www.api.org/~/media/Files/Oil-andNaturalGas/Fuels/Kelleher%20Final%20EV%20Battery%20Reuse%20and%20Recycling%20Report%20to%20API%2018Sept2019%20edits%2018Dec2019.pdf.

Vehicle dismantling

Removing vehicle parts, including the battery, and collecting them for reuse, repurposing, recycling, or sale.

Waste

A used or unused battery becomes a waste on the date the handler decides to discard it.[40] Most batteries meet the definition of dangerous waste (ignitable, reactive, and/or corrosive) but are included in the definition of universal waste. Waste generators are required to evaluate a LIB to determine whether it meets the criteria and qualifies as dangerous waste or universal waste. Businesses may manage spent EV LIBs as a universal waste unless damaged.

[40] Standards for Universal Waste Management, WAC 173-303-573.

Appendix B. Acronyms

DDR

Refers to a damaged, defective, or recalled EV battery.

DIY

Do-it-yourself.

OEM

Original equipment manufacturer. Vehicle manufacturers or battery manufacturers.

EOL

End-of-life.

EPR

Extended producer responsibility.

EV

Electric vehicle.

ICE

Internal combustion engine.

IJA

Infrastructure Investment and Jobs Act.

IRA

Inflation Reduction Act.

ITC

Investment Tax Credit.

kWh

Kilowatt-hour. Measure of a battery's energy capacity.

LIB

Lithium-ion battery chemistry.

LFP

Lithium iron phosphate battery chemistry.

NCA

Lithium nickel-cobalt-aluminum oxide battery chemistry.

NCM

Nickel-manganese-cobalt battery chemistry.

SOH

EV battery state-of-health.

Appendix C. Applicable Codes, Laws, and Regulations

Regulations and standards govern the dismantling and disassembly of vehicles, as well as the transportation and storage of LIBs within Washington state and the U.S. as detailed in Table C-1.

Table C-1. Regulations and codes relevant to EV LIB management within Washington state.

EV LIB Management Activity	Relevant Regulations
Dismantling of a vehicle (Vehicle parts removed and collected, including the battery, and are discarded or recycled)	WA Facility Licensing Requirements: Washington Administrative Code (WAC) High voltage equipment and personnel safety references: NFPA 70B/E; IEEE C2 and IEEE 3007.3; OSHA 29 CFR 1926 and 1910 WA Fire and Building Codes and Standards: 2021 WA State Fire Code, and amendments of Chapter 12 of the 2021 edition of the International Fire Code; 2023 edition of NFPA 855 for the Installation of Energy Storage Systems (extended) WA Standards for Universal Waste Management: WAC 173-303-573
Shipping and Transport of an EV LIB	Hazardous Materials Regulations, U.S. DOT: 49 CFR §173.185
Storage of an EV LIB	WA Fire and Building Codes and Standards: 2021 WA State Fire Code, and amendments of Chapter 12 of the 2021 edition of the International Fire Code; 2023 edition of NFPA 855 for the Installation of Energy Storage Systems (extended) Federal Universal Waste Regulations: 40 CFR §273.15 WA Standards for Universal Waste Management: WAC 173-303-573
Disassembly (Vehicle parts removed and collected, including the battery, and reused or remanufactured) **Under WA Standards for Universal Waste Management, batteries that no longer serve their intended purpose are considered waste.*	WA Facility Licensing Requirements: Washington Administrative Code (WAC), Title 46. High voltage equipment and personnel safety references: NFPA 70B/E; IEEE C2 and IEEE 3007.3; OSHA 29 CFR 1926 and 1910 WA Fire and Building Codes and Standards: 2021 WA State Fire Code, and amendments of Chapter 12 of the 2021 edition of the International Fire Code; 2023 edition of NFPA 855 for the Installation of Energy Storage Systems (extended) *Repurposed Batteries (designated as waste):* WA Standards for Universal Waste Management: WAC 173-303-573

Energy Storage System (ESS) Installation	WA Electrical Storage Requirements: 2021 WA State Fire Code, and amendments of Chapter 12 of the 2021 edition of the International Fire Code; 2023 edition of NFPA 855 for the Installation of Energy Storage Systems (extended)
Hazardous Waste Handling, Treatment, Storage, and Disposal	Federal Universal Waste Regulations, Standards for Destination Facilities: 40 CFR §273, Subpart E Permitting requirements: 40 CFR §124 and 40 CFR §270 Standards for hazardous waste treatment, storage, and disposal facilities: 40 CFR Parts 124, 264, 265, 266, 268, and 270 Notification requirement: Section 3010 of Subtitle C of the Resource Conservation and Recovery Act (RCRA)

Appendix D. Example Interview Questions

Below is an example set of interview questions that the consultant team used in industry stakeholder interviews.

General

1. What does your day-to-day involvement with EV batteries look like? How does your company/organization interact with EV batteries?
2. Roughly what volume of EV batteries is your industry currently interacting with at end of life

End-of-life process

1. What are the common pathways for batteries at the end of their life in the original vehicle?
    a. For an intact car with a battery at EOL?
    b. For a wrecked car with a functioning battery?
    c. What are relevant financial considerations for various end-of-life pathways?
2. At what point are batteries removed from vehicles?
    a. What are the common methods of battery removal, and who carries out this process?
    b. How much time/cost does it take to remove a battery pack?
    c. Do you know of sites where battery packs are removed from vehicles?
3. Are there methods to tell if a battery is damaged? If so, please explain.
    a. What information would be useful for salvage yards to flag if a battery is damaged?
    b. What about its general state of health?
4. How is it determined whether a battery is worth reselling?
    a. Who makes this determination?
    b. Are there records of sales and buyers?
5. Who makes the determination of whether or not a battery is suitable for reuse?
    a. When is this determination made?
    b. How is this determination made?
    c. What is the tipping point that determines that a battery has negative value?
6. Who sells EV batteries?
    a. Where are they sold?
    b. How much are they typically sold for? (a range is fine)
    c. Who buys EV batteries?
        i. What are the financial motivations for buying used EV batteries?
7. At what point are batteries fully discharged for safe transport and storage or recycling?
8. Can you describe the process of how batteries are shipped when they leave your facility?
    a. Can you describe the players involved in the shipping process?

    b. Can you describe shipping methods used for batteries?
    c. Who pays for the shipping?
    d. What types of containers are used to ship batteries?
    e. Do shippers assume responsibility for the safety of the batteries during shipping?
9. Where are EVs (and batteries) ending up?
    a. Do they leave the state?
    b. Do they leave the country?
10. What do you see as the biggest challenges to the end-of-life process for EV batteries?
11. What do you see as the biggest opportunities for the end-of-life process for EV batteries?

Storage and stockpiling

1. Where are EV batteries stored or stockpiled once they are removed from vehicles?
    a. Are there specific facilities designated for their temporary storage?
    b. What safety measures are in place?
    c. Do you know of specific locations where batteries are stored or stockpiled?
2. Is there anything specific that concerns you about the storage and stockpiling of EV batteries?

Disposition pathways

1. What happens to EV batteries after they are collected?
    a. Are they sold to a secondhand market?
    b. Sold to battery recyclers?
    c. Disposed of?
    d. Other?
    e. Do you have any insight as to roughly what percentage of EV batteries are reused after the original vehicle usage versus recycled?
2. Where and how do auto recyclers acquire EVs?
3. How do you handle batteries that are going to different disposition pathways?
4. What are the existing practices and infrastructure for each of these pathways?
5. Are there barriers or exceptions to recycling?
    a. How would you ease these barriers?
    b. What standardization can be applied to battery pack design to support efficient recycling?

Battery chemistry considerations

1. Are you able to differentiate between battery chemistries
    a. If yes, does this contribute to safety considerations?
    b. If not, what would be helpful to help differentiate between chemistries?
2. Would you potentially be supportive of nuanced regulations to support the differing safety considerations of varying battery chemistries?

    a. What about nuanced regulations to support the differing economic considerations of varying battery chemistries?
    b. Are there existing regulations or incentives that best support recycling certain battery chemistries?

Regulatory framework

1. How do current regulations and guidelines regarding EVs and EV batteries impact your industry segment?
    a. What specific regulations apply to your industry segment
    b. Which are most burdensome?
    c. Which are most supportive?
    d. Do any of these regulations address environmental protection and public safety?
2. What regulations or guidance would be helpful for your industry to function most effectively to enable safe handling, storage, transportation and ultimately recycling of Li-ion batteries?
    a. Are there existing regulations, policy proposals or guidelines in WA that you would like to see changed?
3. Are there existing regulations, policy proposals, or guidelines from other states that you would like to see in WA
    a. Are there regulations, policy proposals, or guidelines from other states that you *don't* want to see in WA?

Conclusion

1. Please describe information gaps or education needs to help your industry segment.
    a. Would it be useful to have more information about:
        - Safe handling and storage best practices?
        - Differences in battery chemistries and corresponding flammability if damaged
2. Can you describe ways your industry can help fill information gaps that may exist to better inform stakeholders, policy makers and the public about how your industry functions and the important role it plays with EV batteries?
3. In an ideal world, what would you see as the best practices for your industry related to EV Battery end-of-life and recycling?
4. Are there any suggestions for best practices you would like to share with other stakeholders in the EV battery industry?

Appendix E. Example Survey Questions

Washington State Electric Vehicle Battery Management Survey

SECTION 1. Below are questions about your involvement with electric vehicle (EV) batteries.

Please select what best describes your organization or involvement with EV batteries.

- o Academic
- o Auto Auction Company
- o Auto Recyclers
- o Auto Repair
- o Automaker
- o Battery Original Equipment Manufacturer (OEM)
- o Community-Based Organization
- o Emergency Management
- o Environmental Group
- o Insurance Adjuster
- o Individual DIY reuse
- o Interested Individual
- o Li-ion EV Battery Recycler
- o Traditional Battery Recycler
- o Local Government
- o Reuse market
- o Reverse Logistics and Transportation
- o Solid Waste Management
- o State Government
- o Towing Companies
- o Other (fill in the blank)____

Please describe your day-to-day involvement with EV batteries.

Please enter an estimate for the number of batteries your organization works with on an annual basis.

SECTION 2. The regulatory landscape for the management of EV Batteries is evolving at both the state and federal levels. Regulations and laws may change based on federal level policy decisions. Below, questions invite stakeholders to provide input on codes, regulations, and policies. You may skip questions for which you do not have an answer or are unable to share an answer.

1. What codes, regulations, and policies are you aware of that apply to your EV (and EV battery) practices or are of interest to you?
2. What changes to the existing codes, regulations, and policies would you suggest? Please list or describe the code along with the desired revision(s).
3. Are there additional codes, regulations, and policies that you feel are important to EV battery management in Washington state and are worth considering?
4. What information would help people in your industry, sector, or community to better access or understand codes, regulations, and policies?

SECTION 3. The Department of Ecology has been tasked to develop recommendations for EV battery management in Washington with the help of stakeholders. EV battery management programs and potential policies could take many forms and have different goals. Please indicate your support for the following possible priorities or policies of an EV battery management program. Some of the items listed may or may not fall under the jurisdiction of Washington state. We list them here to capture the broader interests and needs of stakeholders.

Please indicate your level of support for the following priorities from Strongly Oppose to Strongly Support.

1. Access to battery information from the original equipment manufacturer (OEM).
2. Access to battery chemistry information.
3. Access to information on battery health for reuse, resale, or repurposing.
4. Increased transparency and standardization within the battery recycling and automotive salvage/dismantling communities.
5. Increased transparency of the battery supply chain.
6. Streamlined and coordinated rules for within-state EV battery transportation.
7. Development of an exchange program for li-ion EV batteries (cores) similar to the program for lead acid batteries.
8. Advancement of EV battery reuse or repurposing industries.
9. Advancement of EV battery recycling industries.
10. Safe removal, handling, and transportation of EV batteries.
11. Reduction in environmental and community hazards posed by EV batteries
12. Increased efficiency in the removal, handling, and transportation of EV batteries.
13. Reduced cost of locating EV battery processing facilities in Washington from increased ease of permitting.
14. Access to diagnostic tools for entities who interact with used EV batteries or damaged electric vehicles.
15. Clear battery ownership guidelines to remove ambiguity concerning environmental liability.
16. Clearly defined responsibility for EV battery end-of-life processes including reuse, refurbishment, and repurposing.
17. Clearly defined responsibility for the payment of recycling EV batteries that cost more money to collect and recycle than the value of their materials
18. Access to information about how to respond to EV battery fires.
19. Training for emergency responders on how to fight EV battery fires.

Are there other priorities that Washington state should consider for EV battery collection and management?

Please share your level of support for the following possible policy options from Strongly Oppose to Strongly Support.

1. Require a digital identifier on every EV battery to access information about the battery.
2. Require a physical written label on every EV battery with information about the battery.
3. Assign a battery identification number (similar to a VIN for cars) to EV batteries.
4. Incentivize the development of a universal diagnostic system for EV battery health.
5. Create an online database for tracking and reporting lithium-ion batteries that are end-of-life (for the purposes of this survey, a battery is at the end-of-life when it is done with its original use in a vehicle).
6. Require companies that are recycling batteries to report their total recovery rates, as well as the recovery rates of cobalt, lithium, manganese, and nickel.
7. Require pre-approval from interested parties to bid on EVs at auctions to enable tracking of EV batteries purchased at auctions.
8. Incentivize EV battery research and development, including businesses that focus on reusing and repurposing EV batteries.
9. Encourage the insurance industry to provide coverage for out-of-warranty batteries and/or batteries refurbished for ongoing vehicle use.
10. Ensure eligibility of used EV batteries for use in existing and new grid-related incentive programs.
11. Modify Washington State Dangerous Waste Regulations to have EV batteries only be considered waste after it has been shown that they cannot be recycled, to make it easier for the materials such as lithium, cobalt, and other critical materials to be reused.
12. Provide EV battery recycling incentive packages such as tax breaks or grants.
13. Establish battery rebates, returnable deposits, or recycling stipends to encourage consumers to recycle batteries.
14. Develop an end-of warranty battery exchange program that would encourage consumers to turn in EV batteries for new or refurbished EV batteries.
15. Support the enforcement of unlicensed dismantling laws to prevent environmental hazards and stranded batteries.
16. Develop training materials on safe and efficient transportation, handling, management, and collection.
17. Support transportation research for safe and efficient removal, handling, and transportation of EV batteries.
18. Develop strategic collection and sorting facilities in WA state to reduce transportation costs.
19. Clarify and harmonize regulations that pertain to the transportation of batteries within WA state.

20. Require producer take-back with companion legislation requiring return of lithium-ion batteries to the original equipment manufacturer at end-of-life.
21. Apply an environmental handling fee at the time of purchase to finance a collection, recycling, and safety program.
22. Apply a fee that is split between the EV owner and auto-manufacturer at the time of purchase to finance a collection, recycling, and safety programs.
23. Provide financial incentives in the form of tax breaks or incentives to facilities who disassemble EV batteries.
24. Require recovery rates for specific critical materials in batteries such as cobalt, nickel, lithium, and copper.
25. Require or incentivize original equipment manufacturers to design EV batteries in a way that makes repurposing, reuse, and recycling less time and cost intensive.
26. Develop a process standard for the disassembly, processing and recycling of lithium-ion batteries that can be verified by a third party to guarantee a minimum environmental standard.
27. Require recycled content standards for EV battery manufacturers.
28. Require original equipment manufacturers (OEMs) to provide information on how to respond to fires due to EV batteries they manufacture.
29. Fund the development of protocols and training for the emergency response community to respond to EV battery fires.

What other policy options should Washington state consider?

We would like to thank CalEPA's Lithium-Ion Car Battery Recycling Advisory Group (2022 Final Report) and Colorado State University's Thomas H. Bradley and Timothy C. Coburn (2021 Colorado EV battery recycling study) for their efforts designing policies which informed the options in this section of the survey. A number of potential priorities and policies listed in this section were adapted or came directly from these reports.

Your answer to the following question will determine which of the remaining sections of the survey you will answer. You may always select a section now and skip questions later if they are not relevant to you.

We invite you to help us build a more complete understanding of EV battery management that will be shared with you and the general public. The information you share will help inform future policy recommendations.

Please select all of the following content areas that you have knowledge in, or would like to provide input on:

- ▢ EV battery removal
- ▢ EV battery testing and repair
- ▢ EV battery storage and stockpiling
- ▢ EV battery resale
- ▢ EV battery reuse
- ▢ EV battery recycling
- ▢ EV battery disposal or abandonment
- ▢ EV battery chemistry considerations
- ▢ Community interests in EV battery management
- ▢ Environmental and Environmental Justice interests in EV battery management

Note: The sections for each content area often use similar, although not identical questions. A sample of select content area questions is included below.

SECTION 4. Below are questions about what happens to EV batteries at their end-of-life. For the purposes of this survey, a battery is at the end-of-life when it is done with its original use in a vehicle. You may skip questions for which you do not have an answer or are unable to share an answer.

What are the common pathways for EV batteries at the end of their life in their original vehicle? Please select all that apply:

- ▢ I don't know
- ▢ Repair
- ▢ Storage or Stockpiling
- ▢ Resale
- ▢ Reuse
- ▢ Recycling

- ▢ Disposal or Abandonment
- ▢ Other (fill in the blank) ____

What factors determine the pathway an EV battery takes? (Choose all that apply)

- ▢ I don't know
- ▢ Economics/price
- ▢ Battery chemistry
- ▢ Logistics
- ▢ Battery health or condition
- ▢ Regulations
- ▢ Other (fill in the blank) ____

Please share any additional information you have on what determines which pathway an EV battery takes.

What methods are there for determining if an EV battery is damaged?

Are people in your industry, sector, or community able to determine a battery's health?

- o Yes
- o No

What methods are there for determining an EV battery's health?
If your organization or industry uses a diagnostic tool, then please share any information that you can about it.

How does battery health contribute to safety considerations for your industry, sector, or community?

What would be helpful to better identify the health of an EV battery?

Why is an EV battery typically removed from a vehicle?

- ▢ Battery's state of health (SOH) is less than the warrantied percentage
- ▢ Battery is damaged
- ▢ Vehicle is damaged
- ▢ Other (fill in the blank)

What are best practices for battery removal?

Where do batteries go after removal?

What amount of EV batteries do you estimate are being reused annually?
Please include a **number** (e.g. "1,500"), **units** (e.g. "batteries", "tons of batteries", or "MWh batteries"), and **scale** (e.g. "at my recycling facility," "in WA state", or "in the U.S.")

What industries, organizations, and/or individuals are reusing EV batteries?

What are the supply sources for reused batteries?

SECTION 5. Below are questions about the process of removing EV batteries from EVs. You may skip questions for which you do not have an answer or are unable to share an answer.

In your line of work, who removes EV batteries from the original vehicle? Please select all that apply.

- ▢ I don’t know
- ▢ Trained EV repair mechanics
- ▢ Any mechanic
- ▢ Anyone
- ▢ Auto dealer
- ▢ Auction house
- ▢ Salvage or towing yard
- ▢ Other (fill in the blank)

SECTION 9. Below are questions about the reuse and repurposing of EV batteries after they are separated from their original vehicle. Reuse is defined here for the purpose of this survey as individuals or organizations **taking an EV battery that is no longer in its original vehicle and using it in another vehicle, a stationary energy storage system, or for another purpose.** Reuse can include the process of refurbishing the battery for another purpose outside of the original vehicle. You may skip questions for which you do not have an answer or are unable to share an answer.

How are EV batteries being reused?

What are the existing practices for reuse? (e.g. procedures for safe handling, safe operation in new use, battery diagnostics and health, etc.)

What do you think would be the best practices for reusing EV batteries?

What are barriers to best practices for reusing EV batteries?

What concerns do you have about the reuse of EV batteries?

SECTION 10. Below are questions about the recycling of EV batteries. The **first 8 questions** will ask about the **battery recycling process,** while the remaining 5 questions will ask about **transportation and reverse logistics for EV battery recycling**. You may skip questions for which you do not have an answer or are unable to share an answer.

What amount of EV batteries do you estimate are being recycled annually?
Please include a **number** (e.g. "1,500"), **units** (e.g. "batteries", "tons of batteries", or "MWh batteries"), and **scale** (e.g. "at my recycling facility," "in WA state", or "in the U.S.")

What are the existing practices for recycling EV batteries?

What do you think would be the best practices for recycling EV batteries?

What are barriers to best practices for recycling EV batteries?

What concerns do you have about the recycling of EV batteries?

What are the sources of revenue resulting from recycling EV batteries?

What, if any, are the near- to medium-term barriers to making EV battery recycling economical?

Where are EV batteries currently recycled? (Recycling describes the processing of EV batteries for materials. The collection of EV batteries is not considered recycling). **Please select all that apply.**

- ▢ I don’t know
- ▢ Within WA state
- ▢ Within the United States
- ▢ Outside of the United States
- ▢ Other (fill in blank) ____

What are the supply sources for EV battery recyclers? (e.g. auto recyclers, vehicle auctions, third party battery collectors, etc.)

What is the process for transporting sourced EV batteries to recycling locations?

How must EV batteries be prepared for transportation to recycling locations?

What are the costs of transporting EV batteries to recycling locations, and who pays them?

What happens to EV batteries with materials valued less than it costs to transport and recycle them?

SECTION 13. Below are questions about the chemistry of EV batteries. You may skip questions for which you do not have an answer or are unable to share an answer.

Are people in your industry, sector, or community able to differentiate between battery chemistries?

- o Yes
- o No

How do they differentiate between battery chemistries?

What would be helpful to better identify the battery chemistry of an EV battery? Please be as specific as possible.

How does battery chemistry contribute to safety considerations for your industry, sector, or community?

How do differing battery chemistries affect where batteries go at their end-of-life?

How does battery chemistry influence the value of a battery for your industry, sector, or community?

SECTION 14. Below are questions about your community's interests in the management and collection of EV batteries. You may skip questions for which you do not have an answer or are unable to share an answer.

What are your community's interests for EV battery management and collection?

What do your community think would be the best practices for the collection and management of EV batteries?

What does your community think are barriers to best practices for the collection and management of EV batteries?

What concerns does your community have about the collection and management of EV batteries?

SECTION 15. Below are questions about environmental and environmental justice concerns with the management and collection of EV batteries. You may skip questions for which you do not have an answer or are unable to share an answer.

What environmental and environmental justice concerns do you have with EV battery management and collection?

What do you think would be the best practices for the collection and management of EV batteries?

What are barriers to best practices for the collection and management of EV batteries?

What are opportunities to support environmental and environmental justice interests through EV battery management and collection?

CLOSING

Is there anything else you would like to share with us?

Would you like to be added to a mailing list to receive updates on webinars, legislative reports, and other engagement opportunities related to this study?

o Yes
o No

Would you be comfortable with us reaching out to you for follow-up on any answers provided?

o Yes
o No

Please provide your name and an email address here if you are willing to be contacted for follow-up on any answers provided:

If you provide contact information, then our consultants will separate your survey responses from your email address before sharing the survey results with the Department of Ecology. Your individual answers to survey questions will be kept strictly confidential.

◯ Name ____

◯ Email Address ____

Appendix F. Webinar Meeting Summaries

Fact-finding webinar

The early portion of the fact-finding webinar was spent providing an overview of the EV Battery Collection and Management Study process. Representatives from the WA Department of Ecology clarified that this process is not currently informing any legislation or rules but is focused on gathering information on current practices and perspectives of those in the EV battery management space.

A representative from a vehicle dealership described in depth the procedure at their location for determining battery end-of-life, removing the battery from the vehicle, storing it briefly, and packaging it appropriately to transport it to another branch of the company. This company's policy is to replace the whole battery unit, and send the old battery back to the OEM, rather than replace specific damaged cells within the battery. The battery's safety plug is pulled to make its connectors dead, but the dealership lacked equipment to discharge the battery cells prior to transport. The representative explained that even if there is residual energy in the battery, if the connectors are dead, the voltage cannot reach the car and it is safe for first responders or vehicle technicians to work around. The removed battery is repackaged in the protective shell that the replacement battery arrived in. The representative explained that there is significant documentation in the transportation process, and that drivers of trucks carrying EV batteries are provided with emergency safety information.

A representative from a different automaker shared that they follow similar procedures to what the first representative shared, but that they have the ability to replace individual damaged battery cells, rather than replacing the whole battery.

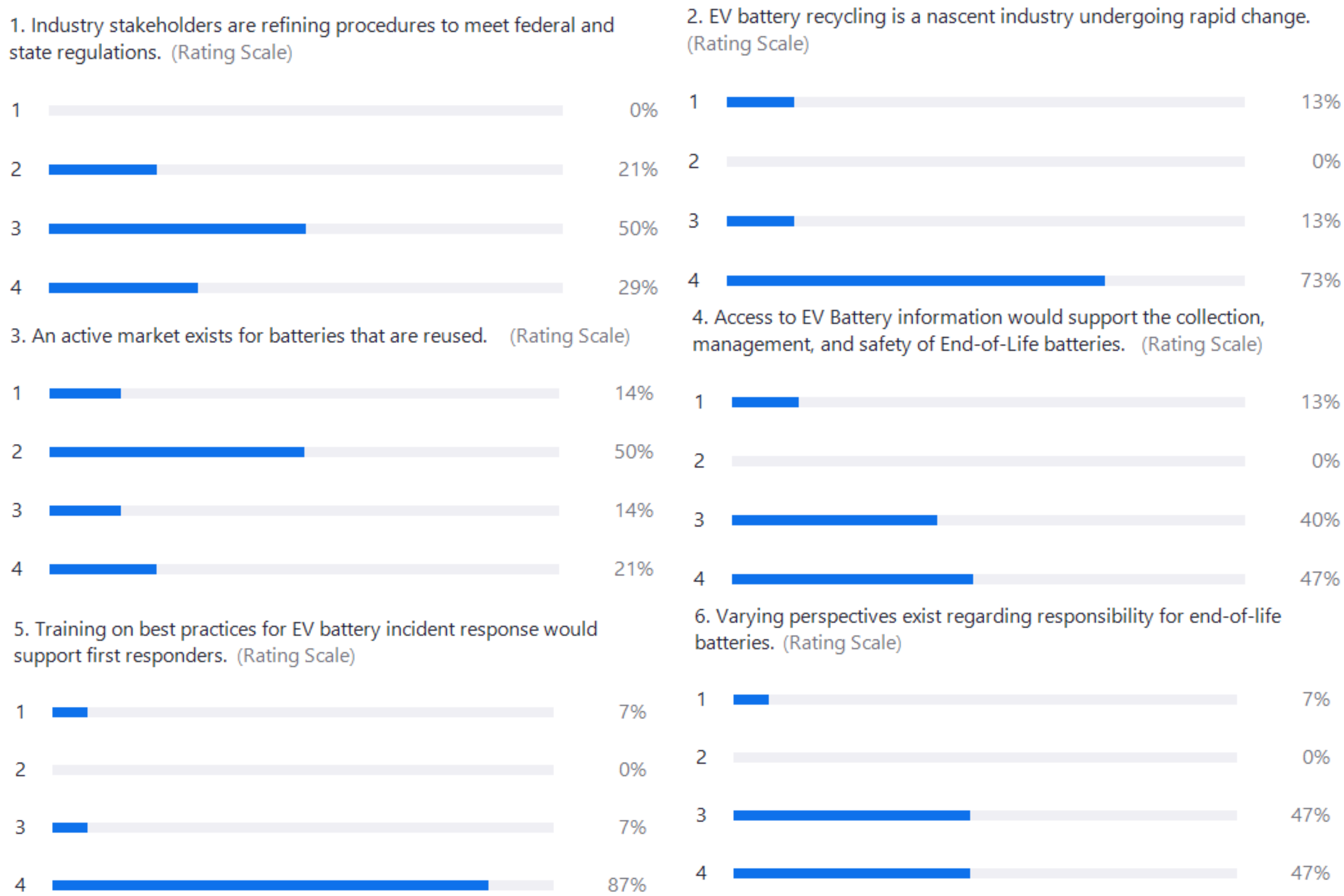
One of the automaker representatives reported that three used hybrid vehicle batteries were abandoned on their dealership lot, and the dealership had to pay for their end-of-life.

A conversation about emergency response to battery fires took place. A representative from an automaker voiced that special equipment and chemicals were required to put out lithium battery fires, and that water cannot be used. A representative from a local fire department countered that statement, by informing the group that emergency services have no special chemicals to extinguish EV battery fires, and instead uses tens of thousands of gallons of water, as recommended by the National Fire Protection Association (NFPA). Another emergency management professional followed that up by stating that local fire services are moving to a stance of non-intervention, and letting EV battery fires burn out, while keeping the fire contained. A large battery recycler stated that they had the chemical agent F500 onsite to extinguish battery fires.

Interested parties webinar

The interested parties webinar sparked a lively conversation around several poll questions, which gauged attendees' perspectives on several emerging themes from research.

Emerging Themes



Figures E-1 to E-6. Poll responses to emerging themes.

The poll responses showed majority strong agreement with the statement “training on best practices for EV battery incident response would support first responders.” Webinar attendees also strongly agreed with the statement “EV battery recycling is a nascent industry undergoing rapid change.” Most respondents also agreed or strongly agreed that access to EV Battery information would support the collection, management, and safety of EV batteries, and that varying perspectives exist regarding responsibility for end-of-life batteries. A more mixed response was received to the statement “An active market exists for batteries to be reused.” Conversations around that question revealed that there was uneven awareness among webinar attendees of the extent of the reuse market. Some webinar attendees in the emergency management sector expressed concern with the safety of EV battery reuse. Respondents recognized that there are individuals and businesses reusing batteries safely and meeting regulatory requirements. Multiple respondents pointed out that many lithium-ion battery fires are coming not from EV batteries, but smaller batteries, like those in micromobility devices.

The interested parties webinar also highlighted that while large vehicle OEMs have well-defined procedures and connections for sending used EV batteries for recycling or remanufacturing, smaller entities do not. One attendee recalled local officials being at a loss for how to deal with an EV battery abandoned in a parking lot. Other more sporadic receivers of EV batteries, like small businesses, (e.g., independent auto repair shops or EV conversion participants) solid waste companies, and the emergency response community, have less awareness of or connections with entities that will collect and recycle the batteries at a reasonable cost.

The respondents in the interested parties webinar were able to highlight areas of a flowchart of EV battery end-of-life pathways, that they felt they understood well, or had questions on. The most questions were marked on what happens when an EV battery goes through a collision, fire, or flood, when an EV battery goes to an auto auction, and when an EV battery goes to DIY reuse, DIY dismantling, disposal, or abandonment. The most well understood pathways were when a battery was within or outside of warranty and goes to a dealership for repair or remanufacturing.

Appendix G. Impacts of the Inflation Reduction Act (IRA) requirements

Impacts of the Inflation Reduction Act (IRA) requirements for domestic products in the tax credit structure for renewable energy are discussed below. The IRA works in conjunction with other incentives, namely the Infrastructure and Jobs Act of 2021 and incentives available within the State of Washington.

Infrastructure Investment and Jobs Act overview

Passed in November 2021, the Infrastructure Investment and Jobs Act (IJA) provides funding for the programs and initiatives listed below, which are designed to address the issues identified in this report.

- Battery and Critical Minerals Mining and Recycling Grant Program ($125 million)
- Earth Mapping Resources Initiative ($320 million)
- U.S. Geological Survey's Energy and Minerals Research Facility ($167 million)
- Rare Earth Elements Demonstration Facility Program ($140 million)
- Battery Materials Processing and Battery Manufacturing Recycling ($2.8 billion)
- Electric Drive Vehicle Battery Recycling and second Life Apps Program ($200 million)
- Advanced Energy Manufacturing and Recycling Grant Program ($750 million)
- Future of Industry Program and Industrial Research and Assessment Centers ($550 million)

Inflation Reduction Act overview

The Inflation Reduction Act (IRA) of 2022 impacts the techno-economics for many energy resources, offering funding, programs, and incentives designed to decelerate energy related emissions. Most provisions of the IRA became effective 1/1/2023 with varying degrees of benefits based on the applicant's ability to meet eligibility requirements.

Taking advantage of IRA incentives, such as tax credits, can create value by leveraging existing zero-emission assets or investments in new technologies. The primary mechanisms that utilities can take advantage of is Investment Tax Credits (ITC) and Production Tax Credits (PTC), which currently provide significant tax rebates on the cost of solar PV, energy storage, hydrogen power systems, microgrid equipment systems, as well as nuclear.

The ITC can help leverage new clean energy investments while the PTC offers benefits for the production of zero-emission energy. The IRA establishes a means for the Tax Code for zero-emission technologies to receive a PTC for manufacturing based on a variety of eligibility factors.

IRA EV benefits

The IRA has many direct benefits to the EV supply chain, manufacturing, and recycling, industrial decarbonization, critical materials processing, refining, and recycling, incentivizing domestic production, and improves supply chains through the following programs:

- Extends and expands the Qualifying Advanced Energy Project Credit ($10 billion)
- Establishes the Advanced Manufacturing Production Tax Credit ($30.62 billion)
- Enhances use of Defense Production Act of 1950 ($500 million)
- Expands the Advanced Technology Vehicles Manufacturing (ATVM) Direct Loan Program ($3 billion)
- Creates the Domestic Manufacturing Conversion Grants ($2 billion) and the Clean Heavy-Duty Vehicle Program ($1 billion)
- Encourages people to buy EVs through the Clean Vehicle Tax Credit, which provides consumers up to $7,500 if they buy a new qualified plug-in EV or fuel cell electric vehicle.
- Aims to strengthen domestic EV supply chains by requiring critical minerals be extracted or processed in the United States or a Free Trade Agreement country, or recycled in North America, with final assembly in North America.

Zero-emission technology

The term 'zero-emission technology' means any technology that produces zero emissions of any air pollutant that is listed pursuant to section 108(a) of the Clean Air Act (or any precursor to such an air pollutant); and any greenhouse gas. The term 'qualified project' includes any project, activity, or technology that— (A) reduces or avoids greenhouse gas emissions and other forms of air pollution in partnership with, and by leveraging investment from, the private sector; or (B) assists communities in the efforts of those communities to reduce or avoid greenhouse gas emissions and other forms of air pollution.

IRA domestic content provision

The IRA treats recycled battery materials as locally "urban mined," or materials recovered from scrap rather than obtained from mining. That has encouraged U.S. companies to move faster on recycling efforts than their counterparts in the European Union, which has focused instead on mandates, including minimum amounts of recycled materials in future EV batteries.

The IRA includes a clause that automatically qualifies EV battery materials recycled in the U.S. as American-made for subsidies, regardless of their origin. This clause is important because it qualifies automakers using U.S.-recycled battery materials for EV production incentives. Boosting responsible domestic production would require leveraging the latest science not only in material extraction but also in developing substitutes and fostering recycling, reuse, and remanufacturing.

Direct Pay option

The concept of Direct Pay originated as part of the 2010 Domestic Manufacturing and Energy Job Act and is utilized in the more recent IRA. The basic mechanism of Direct Pay is that it allows a taxpayer to treat tax credits that they have earned as an overpayment of taxes, allowing the taxpayer to utilize the tax refund mechanism in the tax code to receive a direct payment of cash from the Treasury Department in lieu of monetizing the tax credit through another means. In other words, utilities who are not seeking a profit and therefore do not have a tax burden, can still take advantage of this direct pay option. This opens the door for public entities (municipalities, etc.) to take advantage of tax credits available for qualified projects.

IRA qualifying recycling projects

A qualifying recycling project re-equips, expands, or establishes an industrial or a manufacturing facility to produce or recycle specified advanced energy property (defined in Notice 2023-18[41]). The technology should target an industrial or manufacturing facility to reduce greenhouse gas emissions by at least 20%. Eligible projects for investment tax credits[42] include clean energy and grid manufacturing and recycling projects; industrial greenhouse gas emission reduction projects; and critical material processing, recycling, and refining projects.

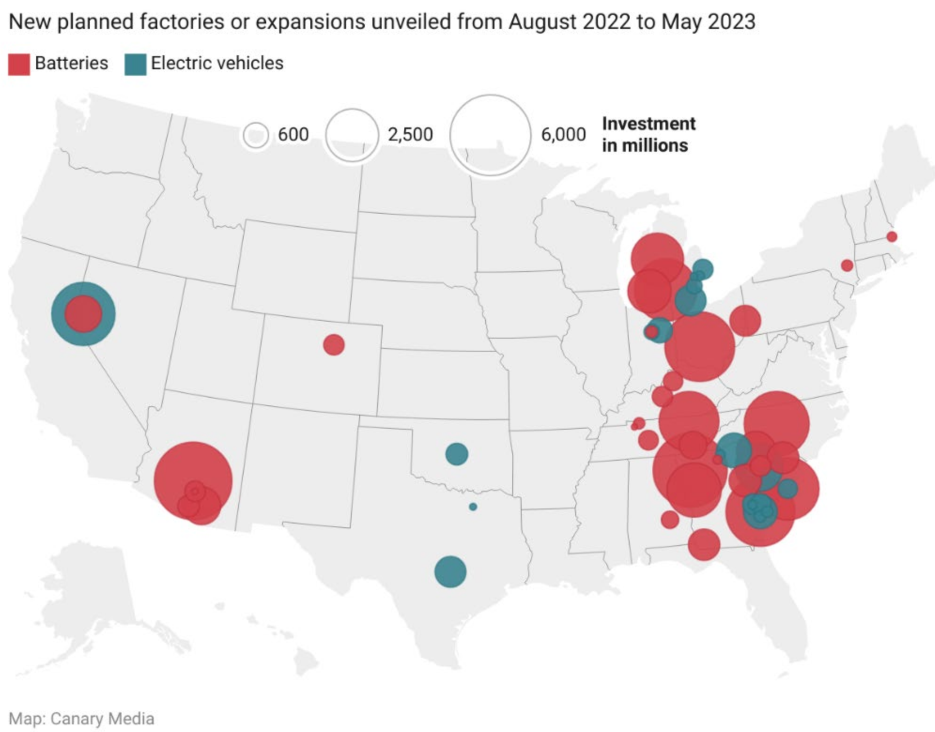


Figure G-17. Battery and EV manufacturing projects announced since IRA passage[43].

[41] Internal Revenue Bulletin: 2023-10 | Internal Revenue Service (irs.gov).
[42] Advanced Energy Project Credit – 26 U.S. Code § 48C.
[43] https://www.canarymedia.com/articles/clean-energy-manufacturing/the-south-is-building-the-most-vibrant-ev-and-battery-hub-in-the-us.