

# Lithium-ion Car Battery Recycling Advisory Group

DRAFT Report

Last Revised: 12/13/2021

Version history:

This version of the report includes all revisions based on comments received on or before 12/10/2021.

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# EXECUTIVE SUMMARY

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## BACKGROUND

The state of California has long been a leader in policies that support electric vehicle (EV) adoption and their success has made California home to 42% of the nation's EV fleet.<sup>1</sup> EVs are powered by lithium-ion traction batteries. As EVs retire from service, a flow of end-of-life (EOL) lithium-ion batteries (LIBs) will be generated. EOL LIBs can be reused, repurposed, recycled or discarded in a hazardous waste landfill. In 2018, California Assembly Bill 2832 (AB2832) required the convening of the Lithium-Ion Battery Recycling Advisory Group whose mandate includes submission of policy recommendations to the Legislature to ensure "...that as close to 100% as possible of lithium-ion batteries in the state are reused or recycled at end-of-life".<sup>2</sup>

## ADVISORY GROUP MEMBERSHIP AND PROCESS

In compliance with AB2832, an Advisory Group was convened and met quarterly between fall of 2019 and spring of 2022. The Advisory Group process was broken in two primary periods; knowledge-building (November 2019-December 2020), and report development (January 2021 – March 2022). The report development period was further divided into four phases: phase 1 (January 2021-March 2021) to identify barriers, opportunities, and the existing landscape; phase 2 (April 2021-July 2021) to identify potential policy options; phase 3 (August 2021-December 2021) to incorporate feedback and create rough draft; phase 4 (January 2022-March 2022) to finalize the report with policy recommendations.

During the knowledge-building period, the Advisory Group heard from 26 experts from industry, academia, and government agencies. In the report development period, Advisory Group members participated in subcommittees to identify barriers and opportunities and to develop policy recommendations specific to three key processes for EOL LIBs: recycling, reuse and repurposing, and logistics. Each subcommittee explored different barriers and opportunities, and put forward proposals for policies.

Based on the proposed policy options and their barriers and opportunities emerging from subcommittees, further deliberation by the whole Advisory Group yielded a final list of proposed policies. Policies were divided into those that define EOL management responsibilities, and supporting policies that help achieve the goal of maximizing reuse and recycling of EOL EV LIBs in a cost-effective manner.

At the November 2, 2021 and December 7, 2021 Advisory Group meeting, the members voted on each policy proposal. Members could either vote in favor, vote to oppose, vote to abstain, or could recuse themselves from the vote altogether. Policy proposals that received at least

majority support from voting members of the Advisory Group are considered to be recommended policies.

## RECOMMENDED POLICIES

### ***Policy proposals that define EOL management responsibility***

Two policy proposals that define EOL management responsibility rose to the level of majority support; *core exchange with a vehicle backstop*, and *producer take-back*. These policies complement, and do not replace, current warranty regulations and programs that require the vehicle manufacturer to properly reuse, repurpose, or recycle a removed EOL battery that is still under warranty.

The **core exchange and vehicle backstop policy** garnered the most support from the Advisory Group at 93% of voting members. It builds on existing industry standards and policies for other vehicle components, specifically a core exchange and product take-back. This policy defines responsibility for out-of-warranty batteries under three possible circumstances:

1. **For EVs still in service**, if a battery pack, module, or cell is replaced before the vehicle reaches EOL, a core exchange program detailed by the EV battery supplier shall be used for the replacement battery (or any module or cell). The entity removing the battery shall be responsible for ensuring the used battery (or module or cell) is properly reused, repurposed, or recycled. The entity selling an EV battery shall use a core exchange program to track that the used battery has been properly managed..
2. **For EVs reaching EOL**, a dismantler who takes ownership of an EOL vehicle is responsible for ensuring the battery is properly reused, repurposed, refurbished, or recycled. If an EV battery is directly reused in another vehicle with no alterations, the process for EVs still in service shall apply. If the battery is refurbished or repurposed, the responsibility transfers to the refurbisher or repurposer.
3. **For EVs reaching EOL** where an EOL EV with an OEM-certified battery is not acquired and removed by a licensed dismantler, the vehicle manufacturer shall be responsible for ensuring that the vehicle is properly dismantled and the LIB is properly reused, refurbished, or recycled.

The other policy proposal that received majority support at 67% of those that voted is a **producer take-back** policy, wherein the auto manufacturer is responsible for ensuring proper repurposing, reuse, or recycling of its EV traction batteries by a licensed facility at no cost to the consumer if and when they are no longer wanted by the owner, and in the event no other entity has taken possession of the battery. Auto manufacturer responsibility initiates when the auto manufacturer has been notified the battery has reached its EOL and is available to be properly managed. If the battery is repurposed, the EOL responsibility transfers to the repurposing company. This responsibility includes: arranging reverse logistics to transport the

batteries to recycling hubs; being responsible for the recycling costs; and documenting the proper disposal of the battery.

The auto manufacturer will also provide educational materials to customers and the service/repair industry, explaining the return process. This material will be made available through the vehicle owner manual or in-vehicle display, in printed dealer materials, and online.

Some identified advantages of both policies include (i) clearly defined responsibility for the EOL battery that transfers if it is repurposed, and (ii) the ability for batteries to be sold to a third party at EOL which provides opportunity for growth in the remanufacturing, refurbishing, and repurposing industry without requiring a partnership with the vehicle OEM. Disadvantages include potentially higher costs for battery suppliers and vehicle OEMs who will likely only be called upon to manage LIBs with negative value.

### ***Supporting policy proposals***

Supporting policy proposals address specific barriers to reuse and recycling and are aimed at ensuring that reuse and recycling processes are safe and environmentally responsible. The proposed policy options are not mutually exclusive and should be considered complementary to the proposed policy defining responsibility for EOL management. In total, 11 of 19 proposed supporting policies garnered majority support, as reported in Table E1. These proposals fall into one of three categories: (i) access to battery information, (ii) support of repurposing, reuse, and recycling industry development, and (iii) safe and efficient reverse logistics. Areas of greatest consensus include reducing the cost of transporting EOL LIBs, and enhancing access to battery information to easily identify the vehicle and battery OEM and improve the efficiency of sorting.

**Table E1:** Supporting policy proposals with majority Advisory Group support

<b>Category</b>	<b>Policy</b>	<b>Purpose</b>	<b>Level of support (%)</b>
Access to battery information	Physical labeling requirement	Facilitate sorting to improve process efficiency; enable easy identification of battery and vehicle OEM	93%
Access to battery information	Digital identifier	Identify LIB chemistry at EOL; identify responsible party for safe disposal; improve safety during disassembly	87%
Access to battery information	Universal diagnostic system	Reduce cost of testing; enable performance guarantees for reused and repurposed batteries	53%
Support repurposing, reuse, and recycling industry	Recycling incentive packages	Mitigate upfront capital costs; encourage recycling within California	73%

<b>Category</b>	<b>Policy</b>	<b>Purpose</b>	<b>Level of support (%)</b>
development			
Support repurposing, reuse, and recycling industry development	DTSC permit timeline	Reduce cost of locating processing facilities within California	60%
Support repurposing, reuse, and recycling industry development	Expand eligibility for battery storage systems	Enable cost-competitiveness with new batteries	67%
Safe and efficient reverse logistics	Support enforcement of unlicensed dismantling laws	Prevent environmental hazards and stranded batteries due to unlicensed dismantling	87%
Safe and efficient reverse logistics	Develop training materials	Improve safety and workforce capacity	93%
Safe and efficient reverse logistics	Support transportation research	Reduce transportation cost	100%
Safe and efficient reverse logistics	Develop strategic collection and sorting infrastructure	Reduce transportation cost	93%
Safe and efficient reverse logistics	Universal waste regulations	Reduce transportation cost and administrative burden	100%
Safe and efficient reverse logistics	Require pre-approval to bid on EVs at auctions	Enable tracking of EVs purchased at auctions	60%

## **CONCLUSIONS**

As the state of California continues its commitment to on-road transport decarbonization and improving air quality through zero-emission vehicle policies, and EVs become more cost competitive and attractive to consumers, the state will see an increasing flow of EOL LIBs that require proper management. To ensure that the maximum amount of EOL batteries are either reused, repurposed or recycled, the Advisory Group’s recommended policies focus on two main areas of need;



- clearly defining responsibility for the coordination and payment of recycling in cases where the cost presents a burden for the owner of the vehicle and the LIB is unwanted and,
- mitigating barriers that may currently inhibit the reuse, repurposing, and recycling of EV LIBs.

The most broadly supported policy defining responsibility for EOL management was the core exchange and vehicle backstop proposal, which allocates responsibility under three possible retirement pathways. The majority of the Advisory Group also supported a producer take-back policy making the vehicle OEM or repurposer responsible for ensuring proper reuse, repurposing, or recycling at a licensed facility and at no cost to the consumer. Under either policy, there should be a clear transfer of responsibility for EOL management when batteries are refurbished or repurposed. Both policies also require further consideration to define what constitutes “proper recycling” and how it should be verified.

Widely supported policies that address more specific barriers include labeling and digital identifier requirements, supporting the development of recycling facilities through incentive packages and a guaranteed permitting timeline, supporting the enforcement of unlicensed dismantling laws, and supporting the development of strategic collection and sorting infrastructure to reduce transportation costs. The Advisory Group also recommended training programs to ensure that the people who handle EOL vehicles have the skills they need to safely work with EVs and assist them in navigating regulatory requirements.

Throughout the process, the Advisory Group members and invited speakers emphasized that EVs are a relatively new technology and are not yet being retired in California at a large scale. Understanding, therefore, that reuse, repurposing, and recycling are still nascent industries, it is important to emphasize that the landscape for EV EOL management is rapidly evolving, and policymaking aimed at supporting reuse and recycling should be iterative. Similarly, as the technologies continue to evolve, different battery formats and compositions may prevail. While the content of critical materials may change, reuse and recycling should remain a priority for the battery as a whole. The recommendations included in this report should be revisited periodically to assess their effectiveness and evaluate whether any changes are necessary.

## ABBREVIATIONS

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<b>Abbreviation</b>	<b>Term</b>
BMS	battery management system
CalEPA	California Environmental Protection Agency
CalRecycle	California Department of Resources Recycling and Recovery
CARB	California Air Resources Board
CCR	California Code of Regulations
CEC	California Energy Commission
CFR	Code of Federal Regulations
CPUC	California Public Utilities Commission
DRC	Democratic Republic of Congo
DTSC	Department of Toxic Substances Control
EOL	End-of-life
E-waste	electronic waste
EV	electric vehicle
g	gram
GWh	gigawatt-hour
IEEE	Institute of Electrical and Electronics Engineers
IOU	Investor Owned Utility
kg	kilogram
kWh	kilowatt-hour
LFP	lithium Iron phosphate
LIB	lithium-ion battery
LMO	lithium manganese oxide
LMO/LTO	lithium manganese with titanate oxide anode
Mt	million metric tons
MWh	megawatt-hour
NCA	lithium nickel cobalt aluminum oxide
NFPA	National Fire Protection Association
NMC	lithium nickel manganese cobalt oxide
OEM	original equipment manufacturer
OSHA	Occupational Safety and Health Administration
RCRA	Resource Conservation and Recovery Act
SGIP	Self-Generation Incentive Program
SOH	state of health
t	metric ton
UL	Underwriters Laboratories
ZEV	zero-emission vehicle

# 1. INTRODUCTION AND BACKGROUND

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## 1.1 ADVISORY GROUP MANDATE

The Lithium-ion Car Battery Recycling Advisory Group (“Advisory Group”) was created in 2018 following a mandate from Assembly Bill 2832.<sup>2</sup> The Advisory Group is tasked with developing policy recommendations aimed at ensuring that as close to 100 percent as possible of lithium-ion batteries (LIB) in the state are reused or recycled, as specified in the bill text:

“(c) On or before April 1, 2022, the Lithium-Ion Car Battery Recycling Advisory Group shall submit policy recommendations to the Legislature...aimed at ensuring that as close to 100 percent as possible of lithium-ion vehicle batteries in the state are reused or recycled at end-of-life in a safe and cost-effective manner. The policy recommendations shall reflect entire life cycle considerations for lithium-ion vehicle batteries, including, but not limited to,

- Opportunities and barriers to the reuse of those batteries as energy storage systems after they are removed from the vehicle,
- Best management considerations for those batteries at end-of-life, and
- The overall effect of different management practices on the environment.

In developing the policy recommendations, the Advisory Group shall consider both in-state and out-of-state options for the recycling of lithium-ion vehicle batteries.”

The Advisory Group first convened on November 18, 2019. Its membership consists of representatives from the following organizations:

1. Alliance for Automotive Innovation
2. CA & NV IBEW-NECA Labor Management Cooperation Committee
3. California Department of Toxic Substances Control (DTSC)
4. California Energy Commission (CEC)
5. California Environmental Protection Agency (CalEPA)
6. California New Car Dealers Association
7. Californians Against Waste
8. California Household Hazardous Waste at large
9. Department of Resources Recycling and Recovery (CalRecycle)
10. Earthworks
11. Ford Motor Company
12. Honda Trading America
13. Kinsbursky Brothers International (KBI)
14. PBRA - The Rechargeable Battery Association

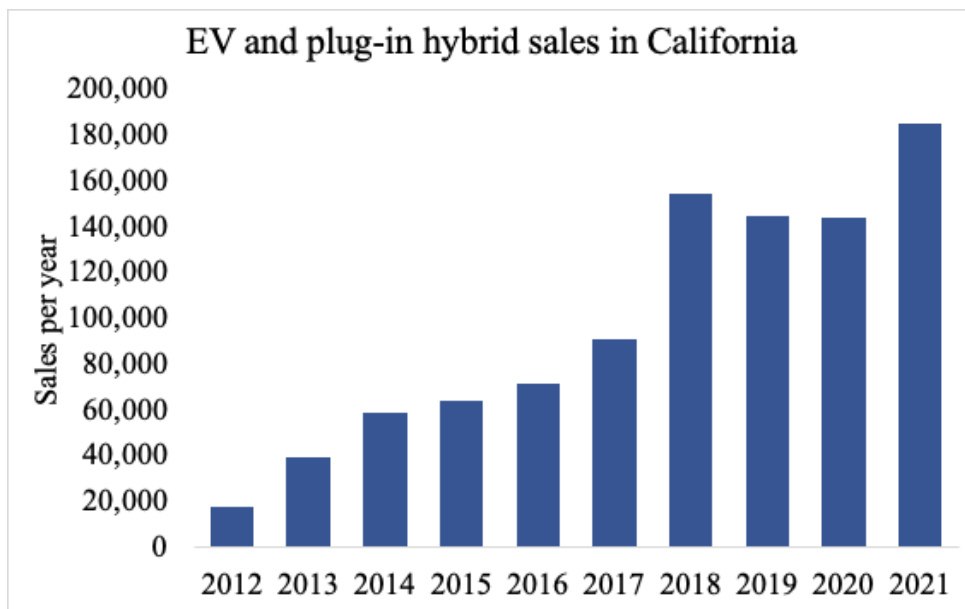
15. SA Recycling
16. Southern California Association of Governments
17. Surplus Service
18. Tesla
19. Umicore USA Inc.

## **1.2 ELECTRIC VEHICLE ADOPTION AND BATTERY TECHNOLOGIES**

Electric vehicle (EV) adoption is a fundamental strategy to decrease greenhouse gas emissions from the transportation sector. Due to ambitious policies implemented by the State of California, adoption has drastically increased over the past decade. The Zero-Emission Vehicle (ZEV) program, first implemented in 1990 by the California Air Resources Board and then restructured in 2012, requires auto manufacturers to produce an increasing number of ZEVs and plug-in hybrids per year.<sup>3</sup>

This policy has resulted in an insurgence of ZEV sales over the last decade, making California home to 42% of the U.S. EV fleet.<sup>1</sup> In 2020 alone, EV sales totaled approximately 144,000, representing 7.7% of all car sales, and 2021 sales are on track to hit an all-time high (Figure 1).<sup>4</sup>

In December 2020, Governor Newsom issued Executive Order N-79-20, setting the goal that all new passenger vehicles sold in California be ZEVs by 2035 and heavy-duty vehicle fleets be ZEVs by 2045.<sup>5</sup> This recent executive order demonstrates the strong commitment to decreasing transport-related emissions through vehicle electrification in California and will lead to continued increases in EV sales.



**Figure 1:** Sales of EVs and plug-in hybrids per year in California as reported by the California Air Resources Board (CARB). Plug-in hybrids are included because the majority are powered by LIBs. The 2021 value represents sales from January to October 29th, 2021.<sup>5</sup>

### 1.3 BATTERY TECHNOLOGY

As the market for EVs has developed, battery design and performance have evolved. United States (U.S.) EV sales show a shift towards significantly higher capacity batteries with longer vehicle ranges.<sup>6</sup> The combination of a ramp-up in the deployment of EVs and the increased size of EV battery systems has dramatically increased the capacity of batteries on the road today. Over 60 GWh of LIBs have been deployed in U.S. light-duty EVs from 2010 to 2020,<sup>7</sup> representing enough energy storage to exceed California’s historical peak electricity load for one hour.<sup>8</sup>

LIBs consist of five key components: cathode, anode, separator, electrolyte, and cell container. The anode is typically made from graphite, the anode current collector is copper, the cathode current collector is aluminum, and the separator and cell container consist of various plastics. The cathode is a lithium metal oxide combined with a transition metal, typically nickel, cobalt, iron, or manganese.<sup>9</sup>

The different LIBs are distinguished by the metals that make up their cathode compound; for example, a battery using a nickel-cobalt-manganese cathode is referred to as an NMC battery. There are also a variety of chemical formulations within different cathode compounds that have important implications for material demand. In an NMC battery, the ratio of nickel and manganese to cobalt can vary from a ratio of 1:1 to 8:1. These variations are communicated via

a number following the battery chemistry: for example, “NMC 622” refers to a LIB with 60% nickel, 20% manganese, and 20% cobalt in the cathode.

The majority of early EV batteries sold in the U.S. were either NCA type (nickel-cobalt-aluminum, used by Tesla/Panasonic), LMO (lithium manganese oxide, used in early Nissan Leafs), or higher-cobalt NMC 111 (nickel-manganese-cobalt).<sup>10</sup> Moving forward, lower-cobalt cathodes such as NCA, NMC 811 and 622, and LFP (lithium-iron-phosphate) are expected to occupy a growing share of the EV battery market.<sup>10,11</sup> Using different metals changes important characteristics such as the energy density, power density, cycle life, safety, and cost of batteries. In addition, replacing cobalt with lower-cost metals influences the profitability of recycling by changing the value of recoverable materials.

## **1.4 CRITICAL MATERIALS FOR BATTERIES**

The term “critical material” refers to materials with high economic importance and high supply risk. Lithium, cobalt, natural graphite, and manganese are all classified as critical materials according to the U.S. Department of the Interior, and nickel is in the process of being added.<sup>12,13</sup> In the Biden Administration’s 100-day supply chain review, lithium, cobalt, and Class I nickel are listed as the most critical battery elements, and graphite, copper, and manganese as “elements of note” that require additional monitoring.<sup>14</sup> Lithium and cobalt are generally considered the most significant supply risk due to the high geographic concentration of production.<sup>15</sup> Nickel has a more stable supply chain than lithium and cobalt, although due to the increasing use of the high purity class 1 nickel, there are expected shortages in the next 5 to 7 years. These supply shortages are a product of underdeveloped production and processing to support upcoming demand and the high import reliance of the US.<sup>14,16</sup>

Establishing a domestic recycling industry presents an opportunity to recover critical materials, thereby reducing reliance on imports and mitigating supply risk. Reducing the environmental and social burden of raw material production, particularly cobalt mining, is an equally important motivation for reuse and recycling. In parallel, identifying domestic resources is another high-priority strategy to increase supply resilience.<sup>16</sup>

The sections below describe some of the resource issues for critical battery materials in greater detail.

### **1.4.1 Cobalt**

Nearly 70% of cobalt is produced in the Democratic Republic of Congo<sup>17</sup> through both industrial mining, which is primarily mechanized, and small scale or artisanal mining, which is practiced manually using simple tools.<sup>18</sup> An estimated 15-30% of the country’s cobalt output is generated through artisanal mining, where adults and an estimated 40,000 children work up to 12-hour days in abusive work environments, exposed to hazardous conditions.<sup>19</sup> Artisanal

miners have little to no protective gear or tools, nor safety measures at mining sites, all while earning less than \$2 per day. A multitude of battery-using companies, from Apple to Tesla, as well as international mining companies, have engaged in programs to either assist local communities to improve economic and educational conditions or to formalize artisanal and small-scale mining enterprises in an attempt to create conditions where mine safety and child labor standards can be improved.<sup>20</sup>

#### **1.4.2 Nickel**

Indonesia is the largest producer of nickel where strip mining for nickel leads to deforestation of tropical rainforests that are home to native people, act as crucial carbon sinks, and provide habitat for endangered species.<sup>17,21,22</sup> After strip mining, the soil is depleted of nutrients, posing a significant challenge to rehabilitation efforts.<sup>23</sup>

#### **1.4.3 Lithium**

Australia has recently become the largest lithium producer, accounting for approximately 49% of global production in 2020 and accessing spodumene, a hard-rock ore.<sup>17</sup> Chile is second in the world for lithium production. Lithium in Chile is produced through evaporation from brines in the Salar de Atacama, a 1,200-square-mile salt flat in Northern Chile. While brine evaporation has typically been the lower-cost and lower-carbon footprint source for lithium, it can consume a substantial amount of water in water-scarce areas.<sup>24</sup> Recently, conflicts over indigenous rights, land use, and water consumption have led to social movements opposing the lithium industry in Chile.<sup>25,26</sup>

Within California, lithium resources have been identified in geothermal brines in Imperial Valley near the Salton Sea. The brine contains various minerals, including lithium, which can be separated using direct lithium extraction technology.<sup>27</sup> An estimated 24,000 mt of lithium could theoretically be extracted annually from existing geothermal plants based on the total throughput of brine in 2019.<sup>28</sup> For reference, the total annual consumption of lithium in the United States from 2016-2020 has been between 2,000 and 3,000 mt.<sup>17</sup> While the environmental impacts of direct lithium extraction have yet to be quantified, they are expected to be substantially smaller than evaporation in terms of water use, energy input, and physical footprint.<sup>29,30</sup>

The feasibility, local impacts, and potential benefits are currently being explored by the Lithium Valley Commission, a blue-ribbon Commission convened by AB 1657 and overseen by CEC.<sup>31,32</sup> As stated in AB 1657, part of the motivation for the Commission is to establish a secure, domestic source of lithium. However, there is currently no refining or cathode production capacity in the United States. Without these steps in the value chain, any materials recovered through recycling or extraction will need to be exported internationally for further processing.

## 2. OVERVIEW OF LITHIUM-ION BATTERY END-OF-LIFE MANAGEMENT

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### 2.1 REVERSE LOGISTICS

Prior to reuse or recycling, LIBs must be removed and transported to the appropriate facility. To accumulate enough batteries for a cost-effective shipment or cost-effective recovery of materials, the batteries may need to be stored for a period of time before shipping. These steps are critical to effectively manage batteries, and there is a complex network of actors involved in safely getting the battery from its point of retirement to its next life cycle phase.<sup>33</sup> The EV and/or LIB may follow one of several pathways depending on whether the vehicle is purchased or leased, and the reasons for retirement.

#### ***2.1.1 Within dealership and original equipment manufacturer (OEM) network***

Leased vehicles or batteries that are under warranty are expected to return to the dealership where they were purchased. For leased vehicles, where the vehicle is intact and the battery has a good state of health (SOH), the returned vehicle may be sold as a used car at the same dealership or sent to a wholesale auction to be purchased and sold by another dealer. Some vehicle OEMs, notably Tesla and Rivian, do not use dealership networks and retain direct customer relationships as well as real-time monitoring of vehicle and battery health. When the vehicle is intact and the battery has a good SOH, the returned vehicle may be sold as a used car through the vehicle OEM's retail system and monitoring of the health of the battery by the vehicle OEM continues.

If the battery is removed under warranty, the vehicle OEM will collect and ship the batteries to a repurposer or recycler (or coordinate the collection and shipment through a third party).

#### ***2.1.2 Outside the original equipment manufacturer (OEM) network***

There is a higher degree of uncertainty surrounding cases where the EV is privately owned and outside of the warranty, since it is a relatively unregulated environment and these batteries have not yet been retired at large volumes. If the battery reaches EOL before the vehicle, it may be taken to a private repair shop that will need specialized personnel to remove and replace the battery. If the vehicle reaches EOL due to a collision, it will likely become the property of the insurance company to be sold at an insurance auction. In California, Copart and IAA are the largest auctions of this type. The auctions are physical locations, but the bidding process occurs online. Licensed dismantlers acquire most of their inventory this way, but any interested party can bid on and purchase a vehicle as well, including parties that may be unqualified to safely repurpose or recycle it. Assuming the EV is purchased by a licensed dismantler, they could then sell the battery to a repair shop, another dismantler, or an individual customer. If the battery



cannot be reused in another vehicle, it should be sent to a licensed repurposer, remanufacturer, recycler, or sorting facility to ensure proper disposal. However, this is not currently required by policy.

Finally, if there is very little value left in the vehicle it could be sent to a scrap metal recycler, in which case the scrap recycler would ultimately be responsible for sending the battery to a sorting, repurposing, or battery recycling facility.

### **2.1.3 Export**

The U.S. is the third largest international exporter of used vehicles after the EU and Japan, exporting approximately 2.6 million vehicles between 2015-2018.<sup>34</sup> This means that significant changes in the vehicle fleet of the U.S. will also have implications for importing countries, particularly as vehicles become electrified. While exporting used vehicles in good condition could improve access to affordable ZEVs and displace low-quality internal combustion engine vehicles in importing countries, it will also shift the burden of battery disposal to the importing countries who may not have the infrastructure to recycle them safely. In addition, if batteries are exported, the U.S. will lose control of the critical materials that could be recovered through recycling.

### **2.1.4 Existing infrastructure**

The dealership, repair, dismantling, and scrap metal recycling industries are well-established, with facilities throughout California. However, the facilities for collecting, sorting, and potentially disassembling (from pack to module) large format LIBs (such as those that will be removed from EVs) are emergent as EVs are only beginning to reach end of life at significant scale. Infrastructure is developing in a piecemeal fashion by vehicle OEMs themselves, through dealerships, and through the repair, dismantling and scrap recycling industries. The largest known facility within California is Retrieval Technology's consolidation location in Anaheim, CA.<sup>35</sup>

## **2.2 REUSE AND REPURPOSING**

Reuse and repurposing are terms often used interchangeably. Here each has a particular meaning; reuse refers to the use of a used LIB in an EV, and repurposing refers to the use of a used LIB in another application (i.e., an application other than as a traction battery in an EV). The reuse and repurposing processes include removal from a vehicle as well as any needed repair, refurbishment, or remanufacturing.

In general, batteries will be retired from use in an EV when the range and performance is no longer acceptable to the driver. The remaining capacity of the battery at the time of retirement will vary depending on consumer preference, but it is generally assumed to be between 70-80%.<sup>36</sup> Given the large capacity and high performance of modern vehicle batteries, retired

batteries could still offer significant value in lower-power, secondary applications, such as storing energy from solar panels to be used in off-grid or peak demand-shaving applications.<sup>37</sup> A growing body of research has examined the environmental impacts and technical and economic feasibility of repurposing batteries for use in second-life applications.<sup>38-42</sup>

Since repurposed batteries are a relatively new phenomenon, data about their performance is uncertain, particularly because of the uneven degradation of battery cells over time. However, it is estimated that battery lifespan can be extended by 10 years or longer depending on the application.<sup>38,43,44</sup> To enable more accurate predictions of battery lifespan and validate the ability of repurposed batteries to provide resilience and load-shifting services, the CEC is funding several ongoing demonstration projects in California (Table 1).<sup>45</sup>

**Table 1:** Repurposed energy storage demonstrations funded by the CEC.

<b>Recipient</b>	<b>Location(s)</b>	<b>Project Description</b>
RePurpose Energy	Grass Valley, CA	Integrated solar + storage system at a food coop to demonstrate energy resilience and test degradation rate.
Smartville, Inc.	San Diego, CA	Integrated solar + storage system at a warehouse to demonstrate demand charge reduction, solar energy shifting, and critical load support and test degradation rate.
San Diego State University	Chula Vista and San Diego, CA	Repurposed battery storage added to existing PV systems at two community centers to demonstrate resilience in the case of a power outage and develop technology to optimize battery health.
ReJoule, Inc.	Signal Hill, CA	Two integrated site demonstrations at a homeless shelter and a commercial building. In addition, ReJoule is developing tools for rapid assessment of the health of retired EV batteries.

In addition to repurposing projects supported by the CEC, several other projects, from demonstration scale (e.g., RePurpose Energy's 300 kWh system at the University of California, Davis Robert Mondavi Institute Winery (Figure 3), to the largest commercial-scale system in North America (B2U Storage Solutions' 8 MWh storage system at a solar PV field) have been installed in California.<sup>46</sup> Outside California, Spiers New Technologies provides repair, refurbishment, and repurposing services in Oklahoma City, OK.<sup>47</sup>

The approaches between companies vary; B2U repurposes entire packs without disassembly, while others reconfigure batteries at the module or even cell level. Testing the charge capacity of packs, modules, or cells, reconfiguring them into consistent packs if necessary, and installing a battery management system (BMS) that can monitor their safety and reliability are some of the key costs that will determine the success of this technology compared to new batteries.<sup>48</sup>



**Figure 2:** RePurpose Energy's 300 kWh system at the University of California, Davis Robert Mondavi Institute Winery (Photo credit: M. Slattery)

## 2.3 RECYCLING

By reducing demand for raw materials, recycling avoids negative environmental and social impacts from mining, and has the potential to grow a domestic supply chain for key battery materials.<sup>49–52</sup> This section describes processes and pathways for recovering recyclable materials from LIBs.

- **Mechanical Pre-Treatment:** After packs are discharged and dismantled, batteries are mechanically shredded. Materials are sorted into plastic fluff, metal-enriched liquid, and metal solids. After sorting, most copper, aluminum, and steel casings are recovered. The remaining material is often referred to as 'black mass' and has relatively high concentrations of nickel, cobalt, lithium, and manganese. From there, materials may be recovered through secondary pyrometallurgical or hydrometallurgical processes.<sup>53</sup>
- **Pyrometallurgical Recycling:** In pyrometallurgical recycling, modules are smelted in a high-temperature furnace (~1500°C) to produce a concentrated alloy containing cobalt, nickel, and copper. These metals can then be extracted using a hydrometallurgical process. The lithium and manganese end up in a slag that can be directly used in the construction industry or processed further to recover lithium.<sup>54</sup>
- **Hydrometallurgical Recycling:** Hydrometallurgical recycling is a chemical process involving leaching, removal of impurities, and separation. Leaching may be followed by solvent extraction and/or chemical precipitation to recover and increase the purity of lithium, nickel, manganese, and cobalt.<sup>53</sup>
- **Direct Recycling:** Any combination of the processes described above where battery components, particularly cathode materials, are recovered in a suitable condition to be

directly used in battery production, without breaking them down into individual material elements.<sup>55</sup> This process is still mostly in the research and development phase, and the ReCell Center at Argonne National Laboratory is leading research and development, while the CEC is funding additional projects at the University of California, San Diego and OnTo Technologies.<sup>55,56</sup>

The environmental emissions vary by recycling process, with hydrometallurgical and direct recycling resulting in lower CO<sub>2</sub> equivalent (CO<sub>2</sub>e) emissions than pyrometallurgical recycling.<sup>57</sup> This is mainly due to the lower energy intensity of these processes in comparison to pyrometallurgy, a process which also recovers less materials, and thus offsets less emissions from avoided virgin material production.<sup>51,58</sup> Scholars have found the environmental impacts of all processes are highly influenced by the carbon intensity of the electricity used to run facilities, and the avoided emissions (which are used to estimate net impacts from recycling) are influenced by the cathode chemistry of the battery being recycling; cobalt- and nickel-containing batteries (i.e. NCA and NMC) result in an overall higher avoided emissions of CO<sub>2</sub>e than LFP due to their associated higher mining and processing emissions.<sup>51,52</sup>

Recovered materials can be used in either a **closed-loop** or **open-loop** recycling system. In closed-loop recycling, material recovered during recycling is used to manufacture the same product, or a similar product serving the same industry. For LIB cathode recycling to be closed-loop, the constituent material must be refined, then resynthesized into a new cathode compound.<sup>59</sup> Open-Loop recycling means recovered materials are used as inputs in a different product system.<sup>60</sup>

### ***2.3.1 Recycling Industry Landscape***

The existing LIB recycling industry has developed around recycling consumer electronics, with the majority taking place in China.<sup>61</sup> Pilot and commercial facilities are operational to a smaller extent in Europe and North America, although many are in the pilot stage with plans for expansion.<sup>62</sup> North America has hydrometallurgical facilities operational totaling a yearly capacity of 42,300 metric tons (t) per year: Li-Cycle corporation has a facility in Rochester, N.Y.<sup>63</sup>; Retrieval Technologies has facilities in Lancaster, OH and Trail, B.C.<sup>35</sup>; Battery Resourcers has a facility in Worcester, MA<sup>64</sup>; Redwood Materials has a facility in Carson City, Nevada<sup>65</sup>; and Lithion has a facility in Ajou, Quebec.<sup>66</sup> There are six additional facilities under development in North America adding an estimated 50,300 t per year of capacity, with company objectives set towards increasing this capacity further.

## **3. REGULATORY LANDSCAPE**

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The U.S. lags behind other countries and regions that are leaders in EV adoption in the extent and complexity of policy and attendant regulation targeting batteries at their EOL.<sup>67</sup> China and

the EU, the two other largest adopters of EVs, both have policies in place or coming online that attempt to enhance the circularity of battery materials and bring or retain LIB supply chains within their respective regions, with recycling of LIBs playing a role in both.<sup>68</sup> Despite the common goal in both regions, and policies that attempt to consider life cycle and supply chain issues, the policies and directives take on very different forms given the distinctive governmental and political structures in each region. In contrast, the U.S. and California regulate activities that are relevant to EOL batteries, but do not have holistic, overarching policies for batteries at their EOL. The following sections will briefly cover the policies managing these batteries in China and Europe, and then discuss the regulations currently impacting batteries retired in the U.S.

## **3.1 LITHIUM-ION BATTERY END-OF-LIFE POLICIES IN OTHER REGIONS**

### ***3.1.1 European Union***

Since 2006, the EU has restricted LIBs from landfilling and required a 50% recycling rate through Directive 2006/66/EC (Battery Directive).<sup>69</sup> This legislation was designed around battery markets dominated by lead-acid and cadmium batteries, and therefore did not support the specific EOL needs of LIBs. In October of 2020, the European Commission proposed repealing the Battery Directive and replacing it with an amendment to Regulation No 2019/1020. The new proposed legislation, referred to as the EU Battery Regulation, aims to decrease the environmental burden of batteries as well as increase the EU-based supply chain by creating sustainability-based barriers-to-entry, thus increasing the competitiveness of local companies.<sup>67</sup>

The proposed EU Battery Regulation contains several measures specific to battery EOL, including:

- Mandated extended producer responsibility (EPR) for proper EOL management and attainment of collection and recycling targets (Measure 10)
- Transfer of EPR when batteries are repurposed in second-life applications (Measure 2)
- A reporting system for EV and industrial batteries, and target EOL collection rates of 65% in 2025 and 70% in 2030 (Measure 4)
- Minimum material recovery rates that must be met or exceeded during each recycling process for cobalt, nickel, lithium, and copper (Measure 5)

In addition, as part of a Strategic Action Plan on Batteries, the European Commission identified the importance of locating more of the battery value chain within the region, including raw material extraction and battery production.<sup>70</sup> Measures in the proposed EU Battery Regulation which pertain to LIB manufacturing include the required use of recycled materials (recycled content), battery labeling, information sharing, and supply chain due diligence.<sup>68</sup>

### ***3.1.2 China***

The Chinese government first began issuing policy to promote LIB recycling in 2012.<sup>71</sup> Later, in 2017, China enacted the Promotion Plan for Extended Producer Responsibility System, which proposed the creation of an LIB recycling system based on the EPR principles.<sup>72</sup> China has implemented the Pilot EV Recycling Initiative in 17 cities/regions, controlling the number of new enterprises involved in recycling to make full use of existing infrastructure.<sup>73</sup> In addition, they launched a Battery Traceability Management Platform to better track EV batteries throughout their life cycle. In 2018, China enacted the Interim Measures for the Management of Recycling and Utilization of Power Batteries of New Energy Vehicles which requires manufacturers to work with recycling companies to improve the recycling process, by labeling batteries and encouraging design for recycling.<sup>72</sup>

Most recently, the Chinese government has put forward a policy proposing to ban, at least temporarily, the use of repurposed batteries in large-scale energy storage applications.<sup>74</sup> The policy does not propose a permanent ban and still allows second-life batteries for small-scale energy storage applications, so the impact of this policy on what could be a nascent repurposing industry, is still uncertain.<sup>75</sup>

### ***3.1.3 International efforts***

The Global Battery Alliance (GBA) is a partnership managed by the World Economic Forum that includes members from “across the battery value chain, the public sector, civil society, and relevant initiatives”.<sup>76</sup> The GBA’s mission includes improving the sustainability of both production and EOL of batteries, with a focus on increasing LIB adoption in the transport and energy sectors, as well as considering battery circularity and human rights-related issues for production. Among other actions, the GBA has supported the development of a recently commercialized product in service of battery reuse and retirement, the Battery Passport. The objectives of the Battery Passport are to prolong the lifespan of a battery and provide clear and transparent information about battery health for enhanced EOL management.<sup>77</sup> Data provided by the Battery Passport is valuable for determining whether a battery should be repurposed or recycled after its first use, and provides repurposers with reliable and detailed information about battery health before purchasing and testing.

## **3.2 LITHIUM-ION BATTERY REGULATIONS AND STANDARDS IN THE UNITED STATES AND CALIFORNIA**

A complex set of regulations and standards cover the logistics, reuse, and recycling of LIBs within the U.S. and California (Table 2). This section identifies and discusses applicable regulations and the EOL phase that they apply to.

**Table 2:** Regulations relevant to the proper disposal of LIBs within California. These regulations are parsed by the regulated activity. Please note many regulations apply to more than one activity and are therefore listed more than once.

Regulated activity	Relevant regulations
Dismantling	<i>Facility licensing requirements:</i> California Vehicle Code Division 5 <i>Fire and building codes and standards:</i> NFPA 855, Chapter 14; 2024 International Fire Code, Sections 321, and related sections in 2024 International Building Code
Transportation	<i>Hazardous materials regulations:</i> 49 CFR §173.185 (special consideration for damaged batteries)
Storage	<i>Fire and building codes and standards:</i> NFPA 855, Chapter 14; 2024 International Fire Code, Sections 321, and related sections in 2024 International Building Code <i>Federal Universal Waste regulations:</i> 40 CFR §273.15 <i>CA Universal Waste Laws:</i> Chapter 23 title 22 of CCR
Disassembly	<i>High voltage equipment and personnel safety references:</i> NFPA 70B/E; IEEE C2 and IEEE 3007.3; OSHA 29 CFR 1926 and 1910 <i>Fire and building codes and standards:</i> NFPA 855, Chapter 14; 2024 International Fire Code, Sections 321, and related sections in 2024 International Building Code <i>Universal waste regulations:</i> 40 CFR §273.15 <i>CA Universal Waste Laws:</i> Chapter 23 title 22 of CCR
Energy Storage System (ESS) Installation	<i>Interconnection:</i> CPUC Rule 21, CAISO/FERC Tariffs <i>Electrical storage requirements:</i> California Fire Code 1206; NFP 855; International Fire Code
Hazardous Waste Treatment	<i>Universal waste regulations:</i> 40 CFR §273, Subpart E <i>Permitting requirements:</i> 40 CFR §§124 and 270 <i>Standards for hazardous waste treatment, storage, and disposal facilities:</i> 40 CFR parts 264, 265, 266, 268, 270, and 124 <i>Notification requirement:</i> section 3010 of RCRA. <i>CA Universal Waste Laws:</i> Chapter 23 title 22 of CCR <i>CA specific:</i> Health and safety division 20 chapter 6.5
Export	<i>EPA:</i> RCRA export requirements for universal waste

**3.2.1 Facility licensing requirements: California Vehicle Code Division 5**

Any entity in California that participates in the vehicle afterlife market must comply with the *Occupational licensing and business regulations* under Division 5 of the California Vehicle Code.

The following chapters are likely to apply to facilities that handle EOL batteries, or are likely to do so in the future:

- Chapter 3: Auto Dismantlers
- Chapter 4: Manufacturers, Transporters, Dealers, and Salesmen

In addition, California Vehicle Code §220 and §221 are relevant as they are used to determine if a business location is considered an auto dismantler and therefore subject to licensing requirements. Of note is that according to CA Vehicle Code §11500, it is unlawful for any person to act as an automobile dismantler without having an established place of business, meeting specified requirements, and having a current, valid license or temporary permit issued by the DMV.

### ***3.2.2 Storage fire codes and standards: NFPA 855, Chapters 14 and 12 of the California Fire Code***

Used batteries must be stored in compliance with local fire codes, many of which are based on Chapter 14 of NFPA 855 and the International Fire Code. NFPA 855 states that collected batteries must be stored so that the terminals are protected either through battery design or protective packaging to prevent short circuits (14.3.1.2). It also includes requirements for indoor and outdoor storage, including but not limited to the following:

For indoor storage (14.4):

- Requires a fire prevention and mitigation plan to be submitted to the authorities having jurisdiction (AHJ) for approval
- Requires that the room be protected by a radiant-energy detection system
- Requires that the building be provided with an automatic fire suppression system
- Requires that the storage space be protected by a water spray automatic suppression system
- Requires the installation of explosion protection

For outdoor storage (14.5):

- Individual pile sizes are limited to 200 sq ft in an area separated from other piles by 10 ft

Storage regulations will be relevant to all entities that store batteries onsite, which may include dealerships, auto recyclers, repair shops, repurposers, and recyclers. Both the International Fire Code and NFPA 855 are currently being adapted.<sup>78</sup> The requirements in NFPA 855 are currently being amended to align with the new Section 321 of the 2024 International Fire Code that provides a comprehensive set of new indoor and outdoor storage requirements for LIBs. California is expected to adopt these new requirements by 2023.



Second-life or repurposed energy storage systems will also need to comply with Chapter 12 of the California Fire Code. Section 1206 addresses electrical energy storage systems, including: permits, construction documents, hazard mitigation analysis, seismic and structural design, vehicle impact protection (e.g., forklifts), combustible storage, testing, maintenance and repair, location and construction, maximum allowable quantities, storage batteries and equipment, fire extinguishing and detection systems, specific battery-type requirements.

### **3.2.3 Universal waste designations: Title 40 of CFR in part 273**

The federal Standards for Universal Waste Management were adopted in 1995 (FR Doc. 95-11143) and are found in Title 40 of CFR in part 273. The U.S. EPA considers batteries to be a universal waste, as defined in § 273.9. The applicability of the universal waste regulations (found in § 273.2 (b)(3)) is due to batteries<sup>1</sup> exhibiting hazardous waste characteristics.<sup>2</sup> While LIBs contain less toxic metals (e.g., no lead or cadmium) than other types of batteries (e.g., lead acid batteries), they can be a safety hazard as they may contain flammable electrolytes and may be considered a hazardous waste under § 261.21(a)(2). The benefit of defining batteries as universal waste is that they are subject to a more streamlined and less complex collection process at EOL to increase proper disposal by the public. The federal regulations require state standards to be either identical or more stringent. The California-specific universal waste laws are in chapter 23 title 22 of CCR and reflect similar requirements.

### **3.2.4 Lithium-ion battery recycling: 40 CFR parts 264, 265, 266, 268, 270, and 124; Resource Conservation and Recovery Act (RCRA) section 3010**

The transportation and storage of LIBs are covered under the universal waste laws, as discussed above, although the recycling of LIBs is considered a hazardous waste treatment. The Standards for Universal Waste Management in 40 CFR §273, Subpart E states the destination facilities are required to follow the hazardous waste treatment regulations and destination facilities are defined as “a facility that treats, disposes of, or recycles universal waste”, therefore it covers the recycling of the batteries. The *Standards for hazardous waste treatment, storage, and disposal facilities* are under 40 CFR parts 264, 265, 266, 268, 270, and 124. These regulations cover the permitting and siting of facilities and the emission and waste disposal requirements.

RCRA section 3010 requires any person that generates, transports, or recycles regulated waste to notify the EPA and have an operating permit. California is an authorized state to provide permits, and the DTSC within the CalEPA is therefore responsible for reviewing applications. Part A of the permitting process outlined in 40 CFR §270.13 requires form 8700-23, which

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<sup>1</sup> Battery is defined in §273.9

<sup>2</sup> Hazardous waste characteristics are found in § 261 Subpart C

provides basic information about the facility. Part B is outlined in 40 CFR §§270.14 through 270.27 and is much more comprehensive, requiring an ongoing review by DTSC that has historically taken an estimated 2 years to complete. The California *Hazardous Waste Control* guidelines applicable to battery EOL in California are found in Chapter 6.5 of Division 20 of the California Health and Safety Code. *Battery Management* is under Article 10.9 and deems the Federal Mercury-Containing and Rechargeable Battery Management Act (P.L. 104-142) as the law of the state.

Finally, businesses who export used batteries internationally must comply with RCRA universal waste export requirements, which are specified in 40 CFR §262. This entails various forms of documentation, including but not limited to contracts, notice of intent, written consent of the receiving country and any transit countries, and confirmation of receipt.<sup>79</sup>

### **3.2.5 Transportation requirements: 49 CFR §173.185**

Lithium-ion batteries are regulated by the Department of Transportation (DOT) as a Class 9 (“Miscellaneous”) hazardous material. Shipping requirements for lithium-ion batteries that are shipped by any mode of transport are specified under CFR §173.185. Paragraph (b)(1) states that “Lithium cells or batteries, including lithium cells or batteries packed with, or contained in, equipment, must be packaged in a manner to prevent:

- (i) Short circuits;
- (ii) Damage caused by movement or placement within the package; and
- (iii) Accidental activation of the equipment.”

The following paragraphs could apply to EOL EV batteries:

- (b)(5): Specifies packing requirements for batteries larger than 12 kg and impact-resistant outer casing
- (d): Lithium cells or batteries shipped for disposal or recycling are exempted from certain shipping and packaging requirements
- (f) Damaged, defective, or recalled cells or batteries are subject to more stringent packaging requirements and must be shipped in a UN-certified container

Batteries are typically shipped through established third-party logistics companies who are certified in hazardous material transportation. Nonetheless, the party who prepares and ships the battery is responsible for ensuring that it is packaged safely and demonstrating compliance with DOT regulations, so knowledge of hazardous material regulations and safety protocols are necessary for dismantlers, disassemblers, and repurposers.

### **3.2.6 Interconnection: CPUC Rule 21, CAISO/FERC Tariffs**

State, federal, and local interconnection regulations will apply to any batteries used in grid-tied applications. In California, the regulations that interconnected battery storage must follow depend on the application of the system (Table 2).

**Table 3:** Battery storage interconnected to the electricity grid within California must comply with the following tariffs.

<b>Application/connection level</b>	<b>Corresponding Tariff</b>
Net-energy metering/ non-export facility	CPUC Rule 21
Participating in wholesale market, connecting to distribution system	FERC-jurisdictional Wholesale Distribution Access Tariff
Participating in wholesale market, connecting to transmission system	CAISO Tariff

Interconnection requirements for net-metering facilities are established by the California Public Utilities Commission (CPUC) under Rule 21. CPUC Rule 21 contains provisions governing, among other bureaucratic procedures:

- Provisions specific to net energy metered facilities
- Technical operating parameters
- Certification and testing criteria
- Technical requirements for inverters

Each Investor-Owned Utility (IOU) is responsible for the administration of Rule 21 in its service territory. The procedures outlined in the IOU Tariffs rely heavily on UL 1741 and IEEE 929 as well as the testing described in *May 1999 New York State Public Service Commission’s Interconnection Requirements* (page 222). Obtaining UL certification, while technically a voluntary standard, is therefore mandatory in practice for grid-connected systems and will require resources that could pose a burden for smaller companies.

## 4. REPORT DEVELOPMENT PROCESS

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The Advisory Group met quarterly and was supported by researchers at the University of California, Davis (UC Davis). The first 14 months of the project, from November of 2019 through December of 2020, were dedicated to knowledge-building. The Advisory Group heard presentations from the UC Davis researchers along with invited speakers from academia, industry, and government agencies. These meetings educated the Advisory Group on LIB technology; environmental, health and safety impacts; current and potential reverse logistics (including dismantling), reuse, and recycling systems; relevant certifications, regulations and standards in the U.S. and California; and worldwide EV battery policies and initiatives. Table 3 describes the content and invited speakers for each meeting.

In January 2021, knowledge-building continued, but the primary focus of Advisory Group meetings shifted to the report development process, which was divided into four phases:

- Phase 1 (January 2021-March 2021): Identify barriers, opportunities, and the existing landscape
- Phase 2 (April 2021-July 2021): Identify potential policy options
- Phase 3 (August 2021-December 2021): Incorporate feedback and create rough draft
- Phase 4 (January 2022-March 2022): Finalize report with recommendations

To address the scope of topics relevant to developing the Advisory Group recommendation, members were divided into three subcommittees, logistics, reuse, and recycling, based on self-selection during Phase 2 of the process. Membership on each subcommittee was as follows:

### ***Logistics:***

1. Alliance for Automotive Innovation
2. California New Car Dealers Association
3. Earthworks
4. Tesla Inc.
5. PRBA – The Rechargeable Battery Association
6. Umicore USA Inc.

### ***Reuse:***

1. CA & NV IBEW-NECA Labor Management Cooperation Committee
2. California Household Hazardous Waste at large
3. KBI
4. Southern California Association of Governments
5. Surplus Service
6. Tesla Inc.
7. PRBA – The Rechargeable Battery Association

**Recycling:**

1. Californians Against Waste
2. CalRecycle
3. Department of Toxic Substances Control
4. Ford Motor Co.
5. Honda Trading America
6. Occupational Knowledge International<sup>3</sup>
7. SA Recycling LLC
8. Tesla Inc.

**During phase 1** (January 2021-March 2021) each subcommittee defined the existing landscape (i.e. current conditions), and identified barriers and opportunities for safe, effective, and economically efficient logistics, reuse or recycling. Outcomes were reported back to the entire Advisory Group during the March meeting of 2021.

**During phase 2** (April 2021-July 2021) each subcommittee developed potential policy options based on addressing the barriers or taking advantage of the opportunities identified during phase 1. Updates to the Advisory Group were provided at the May and July 2021 meetings.

**During Phase 3** (August 2021-December 2021) the Advisory Group developed the final report and recommendations. The outcomes of subcommittee recommendations and group discussions were incorporated into draft report documents prepared by the UC Davis team. The policy options proposed by the subcommittees, which were in many cases elaborated on or altered during Advisory Group meetings, were turned into a survey that was distributed to Advisory Group members to aid in the process of prioritizing or eliminating policy options. The survey results are provided in the Appendix. Advisory group members determined the recommendations through a voice vote at the November 2, 2021 and December 7, 2021 meeting. The survey results and the vote tabulations are noted in the appendix of this report. Finally, Advisory Group members provided final review of recommendations through edits and comments in drafts of this report.

Table 4 summarizes the main presentation topics and the experts who spoke on each topic for all Advisory Group meetings. The subcommittee meetings are described in greater detail in Section 5 of this report.

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<sup>3</sup> Occupational Knowledge International was a member of the Advisory Group until Nov. 3, 2021.

**Table 4.** Summary of Advisory Group meetings

<b>#</b>	<b>Date</b>	<b>Main Presentation Topic(s)</b>	<b>Speakers/Discussants</b>
1	11/18/2019	Bagley-Keene Open Meeting Act AB2832  Current Lithium-ion Car Battery Recycling Landscape  Advisory Group Mission	Salwa K. Bojack, CalEPA;  Mohammed Omer, DTSC
2	01/27/2020	Materials, Reuse, and Recycling of Lithium-ion Batteries for Motor Vehicles  Schedule and Topics for Technical Presentations	Dr. Hanjiro Ambrose, UC Davis;  Mohammed Omer, DTSC
3	05/27/2020	Testing, Reuse and Second-life Applications of Lithium-ion Batteries from Motor Vehicles  Battery Lifecycle Tracking  Battery Second Life.	Dr. Hanjiro Ambrose, Union of Concerned Scientists;  Lauren Roman, Everledger;  Ryan Barr, RePurpose Energy
4	07/16/2020	Fair Political Practices Commission Exemption from Conflict of Interest Code Requirement  Material Recovery from Recycling Lithium-ion Batteries of Motor Vehicles  Battery Recycling	Salwa K. Bojack, CalEPA;  Dr. Hanjiro Ambrose, Union of Concerned Scientists;  Kunal Phalpher, Li-Cycle;  Jeffrey Spangenberg, ReCell Center at Argonne National Laboratory
5	10/13/2020	Electric Vehicle Battery Policies and Initiatives in the European Union  Worldwide Electric Vehicle Battery Policies and Initiatives  The Role of DTSC in California Policy	Dr. Oliver Heidrich, Newcastle University;  Dr. Alissa Kendall, UC Davis;  Dr. Meredith Williams, DTSC;  Valetti Lang, DTSC;
6	12/14/2020	Electric Vehicle Dismantling	Jonathan Morrow, Automotive Recyclers Association;

#	Date	Main Presentation Topic(s)	Speakers/Discussants
		<p>Overview of Draft Policy Recommendations Report Outline and Subcommittees</p> <p>Delegated Bodies under the Bagley-Keene Open Meeting Act of 2004</p>	<p>Dr. Alissa Kendall, UC Davis;</p> <p>Salwa Bojack, CalEPA</p>
7	01/26/2021	<p>Presentation on Used Vehicles and Spent Lithium-ion Battery Exports</p> <p>Updated European Union Battery Directive</p> <p>Battery, Automotive and Recycling Industry Presentation on Applicable Regulations</p> <p>Action to Formally Establish Subcommittee Membership Assignments</p>	<p>Perry Gottesfeld, OKI;</p> <p>Willy Tomboy, Recharge;</p> <p>George Kerchner, PRBA – The Rechargeable Battery Association;</p> <p>Dan Bowerson, Alliance for Automotive Innovation;</p> <p>Todd Coy, KBI;</p> <p>Mohammed Omer, DTSC</p>
8	03/23/2021	<p>CalRecycle Extended Producer Responsibility Programs and Electronic Waste Fee and Payment System</p> <p>Facility Permitting Requirements</p> <p>Discussion of Progress and Ideas Raised in Subcommittee Meetings</p>	<p>Matt Sheehan, CalRecycle;</p> <p>Heather Beckner, CalRecycle;</p> <p>Wayne Lorentzen, DTSC;</p> <p>Muzha Ferouz, DTSC;</p> <p>Lori Koch, DTSC;</p> <p>Meg Slattery, UC Davis.</p>
9	05/25/2021	<p>California Zero Emission Vehicle Market Development Strategy and Permit Assistance Program</p> <p>California Auto Dismantlers Association on Sustainable End-of-Life Policy Solutions for Lithium-ion Batteries</p>	<p>Tyson Eckerle, California Governor’s Office of Business and Economic Development;</p> <p>Manjeet McCarthy, Go-Biz;</p> <p>Tom Novak, Pick-n-Pull;</p>

#	Date	Main Presentation Topic(s)	Speakers/Discussants
		Progress reports from Advisory Group subcommittees.	George Kerchner, PRBA; Alison Linder, Southern California Association of Governments; Mohammed Omer, DTSC;
10	07/13/2021	Industry and Regulatory Challenges and Obstacles  Preliminary Policy Recommendations Survey  Draft Report Revisions and Comments	Lea Malloy, Cox Automotive Mobility;  Meg Slattery, UC Davis;  Jessica Dunn, UC Davis
11	09/28/2021	Automobile Industry Core Exchange and Takeback Concept  Policy Recommendations Survey Results	Dan Bowerson, Alliance for Automotive Innovation;  Meg Slattery, UC Davis; Jessica Dunn, UC Davis
12	10/22/2021	Initial Policy Recommendations Report Draft	Dr. Alissa Kendall, UC Davis
13	11/02/2021	Second Draft of Policy Recommendations Report	Dr. Alissa Kendall, UC Davis

## 5. SUBCOMMITTEE OUTCOMES: BARRIERS AND OPPORTUNITIES

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### 5.1 LOGISTICS

The scope of the logistics committee includes activities that facilitate reuse, repurposing, and recycling, acknowledging that batteries must first be safely collected and transported to realize the benefits of either process. The activities that fall under the scope of logistics include removal of the battery from the vehicle (referred to as dismantling), testing to determine appropriate next use, collection and sorting, transportation, and tracking.

The subcommittee met five times to review the reverse logistics landscape, identify barriers and opportunities to safe and efficient reverse logistics, and ultimately develop a list of policy options to present to the Advisory Group based on addressing the barriers and taking advantage of opportunities that were identified.



**Table 5:** Summary of Logistics Subcommittee meetings

#	Date	Main Discussion Topic(s)	Presenter(s)
1	2/19/2021	Subcommittee chair selection Group discussion defining goal and scope of subcommittee, identifying barriers and opportunities to safe and efficient reverse logistics, and establishing work plan	Meg Slattery, UC Davis
2	3/12/2021	Reverse logistics infrastructure Storage and transportation considerations Relevant regulations	Meg Slattery, UC Davis; George Kerchner, PRBA
3	4/22/2021	Group discussion of potential policy options	Meg Slattery, UC Davis
4	5/18/2021	Battery collection in North America Group discussion of potential policy options SWOT (Strengths, Weaknesses, Opportunities, Threats) Analysis of policy options	Eric Frederickson, Call2Recycle; Meg Slattery, UC Davis
5	6/22/2021	Group discussion of policy solutions and plan for recommendations	Meg Slattery, UC Davis

### ***5.1.1 Barriers to Safe and Efficient Logistics***

The barriers identified by the subcommittee mainly emerge from the structure of the current vehicle afterlife market, fire and other safety risks from LIBs, current regulations, a lack of information on battery history and current condition, and a shortfall in capacity for handling anticipated flows of retired LIBs. The following paragraphs further explore these barriers, which should not be considered an exhaustive list.

#### ***Capturing Out-of-Warranty Lithium-ion Batteries***

Many of the barriers identified stem from the decentralized and unregulated nature of the vehicle afterlife market in the U.S. 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. One of the concerns mentioned by participants was that once vehicles and/or batteries are out of warranty, it is difficult to track them or control what happens. Given the market-driven nature of the vehicle afterlife industry, returning EOL batteries to a domestic reuse or recycling system essentially relies on there being some financial incentive or benefit for doing so to whoever is handling the battery. Reduced battery recycling costs and increased lithium prices make recycling more attractive, which could potentially resolve this issue.

## *Safety*

EV batteries have a significantly higher voltage than batteries previously used in vehicles and pose a threat of electrocution if mishandled. Whoever removes the battery from the vehicle must take certain safety precautions, particularly if the battery is physically damaged. For example, the battery must be drained and disconnected before performing any work on the vehicle or battery. Facilities should also be equipped with appropriate personal protective equipment (PPE), including but not limited to rubber gloves and boots, high voltage-safe tools, matting, and a safety rescue hook. The other key safety issue is fire. In the event of a fire, EV batteries may reach maximum temperatures between 600 and 1000 C due to thermal runaway<sup>80–83</sup>. Facilities can mitigate fire damage by having proper fire suppression capacity onsite (e.g., copious amounts of water, fire blankets) and dismantling and storing EVs in an isolated area away from combustible materials.

The necessity for specialized dismantling creates an opportunity to create skilled jobs within the state of California. To prevent harm and take advantage of the opportunities presented by the EV transition, resources such as information, training, and safety equipment must be widely accessible to anyone who may be in the position to disassemble an EV.

## *Storage*

Because of the safety hazards described above, whoever handles an EOL battery must follow certain storage and transport protocols. As noted in Section 3.2 of this report, storage requirements are defined by the local fire code (NFPA 855, Chapters 14) and include minimum space requirements and fire suppression capabilities. Storing batteries onsite may present a burden and liability, particularly for smaller facilities that do not have sufficient space to hold batteries for extended periods. This was mentioned as a concern for both auto dismantlers and dealerships. Dealership representatives voiced concern about becoming long-term storage sites for batteries, particularly since most EV sales and ultimately returns will take place at dealerships in denser urban areas, where space is scarce and valuable. Meanwhile, dismantlers are concerned about the safety threat posed to their facility and personnel.

While dealerships have connections to the vehicle OEM and their collection network, dismantlers may not have information about where to send batteries. According to an invited speaker from the Auto Recyclers Association, many are currently accumulating them onsite in the absence of a clear directive.

## *Transportation*

The cost of transportation depends on a variety of factors, including fuel cost, distance traveled, transportation corridor, and load size. The transportation corridor is a factor because carriers may charge more to ship to a remote location, as they are less likely to generate revenue

through backhaul. Meanwhile, the load size is important because it is more cost-effective to ship batteries using a full truckload vs. less-than truckload service. Estimates of the cost of transporting EOL batteries vary widely but are estimated on average to contribute 40-60% of the overall cost of recycling.<sup>33,84-87</sup>

To ensure batteries are transported safely, the party handling the battery must comply with hazardous materials regulations for shipping as specified by the DOT, which increases the cost of transportation. Damaged batteries are subject to more stringent transport requirements, as specified by paragraph (f) in 49 CFR §173.185. Specifically, they must be shipped in a United Nations (UN)-certified container, which are custom-ordered from dangerous goods packaging manufacturers at great expense.

### *Unlicensed Dismantling*

According to CA Vehicle Code §11500, it is unlawful for any person to act as an automobile dismantler without having an established place of business, meeting specified requirements, and having a current, valid license or temporary permit issued by the DMV. Licensed dismantlers process an estimated 840,000 of approximately 1.2 million vehicles that reach EOL in California each year.<sup>88</sup> However, an ongoing concern is the rise of unlicensed dismantling in the state, which is problematic because unlicensed dismantlers do not take the same precautions when disposing of hazardous materials and fluids. Unlicensed dismantlers acquire most of their vehicles through auto auctions and dismantle them in various locations, including repair shops, remote areas, parking lots, industrial lots, and residences.

Unlicensed dismantling is particularly undesirable for EVs given the hazards posed by large-format LIBs when handled incorrectly. In addition, it further complicates the EOL chain of custody and may make it more challenging to capture retired batteries for reuse and recycling. Participants representing the dismantling industry identified this issue and are concerned that any added burden imposed on licensed dismantlers will push more vehicles into the unregulated grey market, where it is cheaper to operate.

### *Infrastructure and Capacity Gaps*

Since EVs are not currently being retired at a large scale, California does not currently have the needed capacity in terms of trained personnel to handle high voltage batteries. Lack of infrastructure in California could encourage EV battery retirement in other states or international export. Participants also identified a lack of infrastructure for battery disassembly from pack to module.

## *Regulatory Barriers*

Participants identified several areas where clarity on existing regulations is desired and discussed the need for alignment between federal and state regulations. Clear instructions on navigating hazardous materials regulations and hazardous waste regulations such as packaging, safety, and storage requirements were recommended. Participants also mentioned a need for solutions to minimize the cost of compliance, especially for smaller operations such as independent repair shops or dismantlers.

- *Universal waste classification:* LIBs are classified by DTSC as a universal waste. However, a key point of discussion was defining at what point they become classified as waste, which will affect what activities may be classified as hazardous waste treatment and who may be considered a generator, handler, or treatment facility. This is an issue that affects all subcommittees.

## *Basic Information Needs*

To facilitate an optimal EOL pathway, the parties involved must have access to information about the battery and knowledge of how to handle it safely.

- *Condition of battery:* Information about the condition of the LIB is necessary to enable the party handling the battery to determine the next appropriate use for the battery and what shipping protocol is needed. Specifically, knowing the state of health (SOH) is necessary to determine whether the battery is most suitable for reuse in a vehicle, repurposing for stationary storage, or recycling. In addition, information about the battery's history and whether it had been in an accident would alert the handler to the potential of physical damage so they could take the needed precautions.
- *Battery chemistry:* Knowledge about battery chemistry is most important for recyclers because sorting before recycling makes the material recovery process more efficient. However, this information would also be valuable to the party handling the battery for negotiation purposes, as recyclers may be willing to pay for higher-cobalt or higher-nickel chemistries, or at least cover the cost of transportation.
- *Information about how to safely handle batteries:* Participants pointed out that vehicle OEMs provide training for dealers about how to handle their batteries and vehicles. It was recommended that this sort of information be made accessible and distributed to independent dismantlers, repair shops, and first responders. In addition, it was recommended that agencies provide clear, detailed guidelines on OSHA, storage, and shipping requirements, and make funding available to support videos and other training materials. Currently, information on handling EVs and hybrids is available from the Auto Recyclers Association, Salvage Wire, and the Department of Transportation.<sup>89</sup>

### ***5.1.2 Opportunities and Benefits***

The opportunities identified by the subcommittee mainly reflect the potential to reduce EOL management costs and improve safety, both of which would improve conditions for robust reuse and recycling systems.

#### ***Reduced Cost and Environmental Impact of Transportation***

Given that transportation is estimated to contribute between 40 and 60% of EOL costs, there is a large opportunity to reduce the overall cost of recycling through more efficient reverse logistics.<sup>33</sup> Through increased information along the chain of custody, relevant stakeholders would be able to send batteries directly to the most appropriate destination, thus increasing efficiency and avoiding unnecessary transportation. Reducing the distance traveled also reduces the environmental impact and cost. Another strategy to decrease miles traveled is facilitating a collection system with strategic infrastructure that enables batteries to be regionally accumulated prior to transport to make the shipment more cost-effective and decrease transport related emissions.<sup>90</sup> Finally, the cost of transportation can be reduced by identifying strategies that ease the cost of regulatory compliance without sacrificing the need for safety. This point was brought up frequently in all subcommittees and it has become apparent the regulatory burden must be decreased at the Federal level.

#### ***Increased Recycling Rates***

Improving the collection rate and reducing the cost of transportation would likely increase the recycling rate for LIBs, thus increasing the throughput and economies of scale. In turn, this would allow California and the U.S. to realize the environmental, economic, and social benefits of recovering critical materials from EVs. Participants also pointed out that creating a successful collection program could provide a framework to encourage the recycling of other products such as computers, outdoor power equipment, and solar panels.

#### ***Improved Conditions for Reuse and Repurposing***

Improving the logistics can lead to increased possibilities for testing and tracking which would support the reuse industry by making it easier to determine which batteries are best suited for reuse. In addition, better information about battery storage would increase safety and avoid unnecessary degradation, which will also support reuse.

#### ***Benefits to Dismantling Industry***

In the near term, establishing a robust network and facilitating access to information will provide a solution for people and companies who do not know what to do with stranded

battery packs. As more battery packs come offline, the demand for collection and dismantling has the possibility to create skilled job opportunities within California.

### *Improved Safety*

Better information on proper handling, storage, and shipping protocol will promote safety for all parties involved in EOL management. Access to knowledge about the battery’s condition will also alert the party handling the battery about the need to follow extra precautions or use specialized packaging.

## **5.2 REUSE AND REPURPOSING**

The scope of the reuse subcommittee included both reuse in another vehicle and repurposing for different applications, though as evident in the discussion that follows, the subcommittee mostly focused on repurposing. Table 6 describes the subcommittee meetings and their content.

**Table 6:** Summary of Reuse and Repurposing Subcommittee meetings.

<b>#</b>	<b>Date</b>	<b>Main Discussion Topic(s)</b>	<b>Presenter(s)</b>
1	2/23/2021	Subcommittee chair selection; Group discussion defining goal and scope of subcommittee, identifying barriers and opportunities to safe and efficient reverse logistics, and establishing work plan	Dr. Alissa Kendall, UC Davis
2	3/8/2021	Energy Stationary Storage Testing Standards, Relevant Regulations, Discussion of opportunities and barriers.	Jody Leber, CSA Group; Dr. Alissa Kendall, UC Davis
3	4/19/2021	The Second-life Battery Industry in California; discussion of policy solutions	Freeman Hall, B2U Storage Solutions; Dr. Alissa Kendall, UC Davis
4	5/17/2021	Product Stewardship Programs; discussion of policy solutions	Jeremy Jones, PaintCare; Dr. Alissa Kendall, UC Davis
5	6/22/2021	Discussion of reuse policy solutions, discussion of policy recommendations report plan	Dr. Alissa Kendall, UC Davis

Reuse and repurposing of EV batteries face a number of barriers, opportunities, and benefits that can be grouped into larger themes. Identified barriers include cost, allocation of responsibility, lack of information and data, battery design, and lack of volume for a sustained business plan. Identified opportunities and benefits include reduced environmental impacts relative to alternatives, economic opportunities and benefits, provision of energy storage services, and others such as improved traceability, and disincentives for planned obsolescence.

The following text describes the barriers and opportunities for reuse and repurposing in greater detail.

### ***5.2.1 Barriers to Reuse and Repurposing***

#### *Cost*

For used batteries to be competitively priced against new batteries they must be offered at a discount, which can be difficult to achieve given the falling costs of new batteries and the added cost of repurposing. Reuse or repurposing will also compete with the critical materials contained in the battery; if recovering materials through recycling provides more value than the reuse or repurpose application, the appropriate pathway may be recycling.

The main costs of repurposing come from acquiring batteries, testing to determine state of health, and reconfiguring and equipping batteries with a battery management system (BMS), thermal management, and other required hardware and software. In addition, battery storage systems must meet certain standards, either because they are mandated by law or expected by the market. The cost of obtaining the necessary certification presents a significant burden for repurposers, who are typically smaller startup companies and do not have the same resources to draw from as, for example, OEMs. In addition, the cost of storing batteries onsite, permitting, and complying with the regulations are a strain on the companies, and the added lack of clarity about the regulatory compliance that is, or will be, required may dissuade actors from the market.

The difficulty in competing with new batteries is exacerbated in California because second-life batteries are not eligible for incentive programs like the CPUC's Self-Generation Incentive Program (SGIP), which partially subsidizes the cost of new energy storage systems.<sup>91</sup> Their current exclusion may be due to uncertainty regarding lifespan and performance.

#### *Allocation of Responsibility*

The subcommittee identified the lack of clarity regarding legal obligations and responsibilities for second-life batteries as a barrier to the development of start-ups and partnerships with OEMs. If a battery is repurposed by a third party and not the OEM, several members expressed the opinion that the OEM should not be held liable if there is an accident. Similarly, responsibility for final disposition of the battery (i.e., recycling) remains an open question, especially under regulatory schemes without some form of producer responsibility.

In the case that the vehicle OEM is not liable if the battery is repurposed, they may still be sensitive to negative press in the event of an accident and attendant reputational risks, which could dissuade their participation in arrangements that facilitate second-life uses.

### *Lack of Information or Data*

- *State of health (SOH):* Repurposing and reuse companies need access to information about the battery's SOH to estimate the remaining lifespan and determine whether the battery is suitable for a second-life application.<sup>92</sup> Access to this information could also enable second-life companies to offer performance guarantees, which are especially important given that second-life batteries are competing with new batteries from established, larger manufacturers that provide such guarantees. Without access to manufacturers' BMS, determining the remaining battery capacity requires an expensive and time-consuming testing process.
- *Battery type:* Since most repurposers connect batteries of the same make and model in storage units, the sector would also benefit from increased access to identifying information about the battery type (i.e., chemistry, voltage, and rated capacity). However, Smartville is currently piloting a system that integrates heterogeneous batteries into the same system as part of the CEC's demonstration grant program.<sup>45</sup>
- *Battery history and condition:* Transparent information about the battery history would alert anyone working on the battery to follow special safety protocols, for example if the vehicle it was removed from had been damaged or in an accident.

### *First-life Battery Design*

The repurposing process can be done at the cell, module, or pack level. All of which require removing the pack from the EV, and in the case the pack is broken down to the module or cell level, disassembling the LIB pack. The lack of standardization between vehicle OEMs complicates the secondary market because the disassembly and dismantling process is different for each pack design. Since not all batteries are designed with disassembly in mind, the process can be dangerous and costly.<sup>93</sup>

### *Acquisition Challenges*

The current small scale of EV retirement is a barrier to advancing the second-life industry, although the quantity of EVs currently being retired is low compared to the amount that will retire in the next decade.<sup>10,11</sup> Furthermore, the supply of retired batteries will likely be dispersed between dealerships, auto dismantlers, insurance auctions, and scrap metal recycling facilities, complicating the reverse logistics process and acquisition routes for the second-life industry.

## **5.2.2 Opportunities and Benefits**



### *Environmental Benefits*

Harnessing the remaining usable capacity in retired EV batteries may displace demand for new battery products, which avoids the negative impacts associated with mining, refining, and manufacturing as well as reduces reliance on imported critical materials. On the other hand, if stationary applications can equally be served by chemistries such as LFP, repurposing batteries which contain more constrained energy minerals – cobalt and nickel – may delay the recovery of these critical materials through recycling, which could diminish the environmental benefits of repurposing.

Alternatively, deployment of repurposed batteries may expand the energy storage market, rather than simply displacing new battery production, in which case key environmental benefits may come from supporting storage needs on the grid required to accommodate the renewable energy transition.

### *Economic Opportunities*

A key economic benefit of repurposing is the job creation in California and the U.S. that would accompany the development of a new industry. Another economic benefit is the potential cost savings to the end-user of a second-life battery system, assuming reused or repurposed batteries can be delivered at a lower cost. More affordable energy storage also promotes equity by enabling households and communities who may not otherwise be able to afford energy storage to be more resilient in the face of natural disasters, for example by providing backup power during public safety power shutoff events.<sup>3</sup>

### *Encourage Transparency and Coordination Across the Value Chain*

A battery pathway where reuse occurs followed by recycling requires mechanisms for long term planning and collaboration across the supply chain. In supporting this approach, Advisory Group members identified an opportunity to set expectations and criteria about the traceability and capture of products before they are put onto the market, which would provide a positive example for other industries. Encouraging reuse and repurposing could also enable repurposers to connect with vehicle OEMs, encouraging a feedback loop so OEMs know how to design for repair or repurposing, and design the market to avoid planned obsolescence. Finally, tracking product longevity and resale can be an incentive for brands to manufacture for reuse and repurposing.

## **5.3 RECYCLING**

The recycling subcommittee was formed to identify policy options that address barriers to recycling and opportunities for minimizing environmental and economic cost while maximizing

material recovery. The scope covered includes material recovery via a recycling process. Table 7 summarizes the Recycling Subcommittee meetings.

**Table 7:** Summary of Recycling Subcommittee Meetings.

#	Date	Main Discussion Topic(s)	Presenter(s)
1	02/02/2021	Subcommittee Chair selection Group discussion of goal and scope Group discussion of barriers and opportunities to recycling	Jessica Dunn, UC Davis
2	03/15/2021	Review of goal and scope Review of barriers and opportunities to Recycling Relevant regulations and permitting requirements	Jessica Dunn, UC Davis
3	04/19/2021	Review of barriers and opportunities to recycling Review of relevant regulations and permitting requirements Group Discussion of Policy Solutions	Jessica Dunn, UC Davis
4	05/19/2021	Group discussion of policy solutions SWOT (Strengths, Weaknesses, Opportunities, Threats) Analysis of policy options	Jessica Dunn, UC Davis
5	06/23/2021	Group discussion of policy solutions Report update	Jessica Dunn, UC Davis

The recycling of LIBs at EOL faces a number of barriers, opportunities, and benefits that can be grouped into larger themes. Barriers identified by the subcommittee include existing regulations, cost, near-term low volume of EOL batteries, recycling industry development within the U.S., and lack of information and data. Opportunities and benefits include reduced environmental and social impacts, economic opportunities and benefits, increased safety, and recycling industry growth. The following text outlines the barriers and opportunities in greater detail.

### **5.3.1 Barriers**

#### *Regulations*

The regulatory environment within California, and at the national and international level, is considered a barrier for the LIB recycling industry. There is a lack of clarity as to regulations relevant to LIB recycling and a lack of alignment between regulations at the state and national scales.

A particular barrier within California is the lengthy permitting process for establishing a recycling facility within the state. The hazardous waste permit requires a six-step process designed to protect public health and safety. The process includes a review of the application materials by engineers, a revision period, and a public comment period.<sup>94</sup> DTSC, the department authorized to issue HW treatment permits, is tasked with balancing the speed of permitting and the rigor of review. They have expedited their permitting process to an average of two years<sup>95</sup>, which is still a long and costly timeline for a business developer. There is also added uncertainty for developers because there has not been a hazardous waste recycling facility sited within California in over 8 years, limiting the ability to infer from recent projects what the needs and timelines might be for new development.

This type of regulatory uncertainty makes investment in recycling infrastructure risky and deters industry from development within California. While this report is California-specific, it is important to note that at the national scale there is currently no regulatory alignment of strategies for recovering critical materials within the US, which is a potential barrier consolidating large flows of EOL batteries for recycling. This may change in the near future due to President Biden's Executive Order on America's Supply Chains, which outlined the importance of recycling to securing a domestic supply chain.<sup>14</sup>

### *Economics*

For recycling to proliferate without government intervention it must be economically compelling. While recycling of EV LIBs is starting to become profitable under the right circumstances, logistical costs have proved to be a significant challenge, especially for lower volumes. Moreover, the value of recovered material is uncertain due to the continuous evolution of cathode chemistries, not to mention volatility in metal prices. A key evolution is reduced cobalt in cathode chemistries, due to the high price of cobalt and increasing concerns over human rights violations during its production. This reduction in cobalt reduces the value of the recovered material.

As the industry develops globally and in the U.S, data sharing could assist the government in understanding the economics of LIB recycling and inform necessary steps the government could take to support development of the recycling industry.

### *Supply of Retired End-of-Life Lithium-ion Batteries*

Similar to the barrier identified by the reuse subcommittee, there is no guaranteed stream of EOL LIBs due to both the relatively small volume of EV battery retirements at this time (though this will change in the coming years), and inadequate collection infrastructure. The owner of the vehicle is currently responsible for the EV battery at EOL for vehicles or batteries outside of warranty, which may prevent batteries from reaching recycling facilities if there is a significant

cost to recycle the battery and no clear direction for whom to contact or how to arrange transportation.

Both barriers (high cost and an unclear process for getting an LIB recycled) could result in the international export of EVs or spent LIBs. If LIBs are exported, recoverable critical materials will be lost. Furthermore, exporting spent LIBs could contribute to environmental justice issues if batteries are managed or processed using unsafe practices, an issue which has been documented for LIBS used in consumer electronics.<sup>62,96</sup>

### *Lack of Domestic Value Chain Infrastructure*

Another barrier to the development of an industry within the U.S. is the lack of a LIB battery supply chain in North America to purchase the recovered materials after recycling. While LIB cells are manufactured within the U.S. (e.g., Panasonic for Tesla), there is no production capacity for the precursors to cell manufacturing, such as cathodes. This means recovered material will be exported to produce cathode materials, perpetuating the dependency on international markets for clean energy technologies.

### *Lack of Information*

Recycling facilities operate at maximum efficiency when the batteries are processed in uniform batches. Identifying information about the cathode chemistry, anode chemistry and electrolyte type is not easily accessible, which adds time and cost to the recycling process.

## **5.3.2 Opportunities and Benefits**

### *Reduced Environmental & Social impact*

The recycling of LIBs will reduce environmental impacts by offsetting demand for primary materials with the recovered materials. This in turn, conserves resources and maximizes the use of existing materials already extracted. This reduced ore extraction minimizes environmental and social impacts, such as those that arise from cobalt mining in the Democratic Republic of Congo. Locally, the recycling of LIBs will conserve landfill capacity and reduce the reliance on hazardous waste landfills. Proper management will also reduce the risk of fire or leaching of toxins that could occur if the battery is not stored or otherwise managed properly at EOL.

### *Economic Opportunities*

The development of a recycling industry within the nation and within California presents an opportunity to create jobs that require a skilled labor force. In addition, there is the economic opportunity of reducing reliance on overseas materials and the risk of supply disruption due to geopolitics. By recycling within the nation, the recovered materials can be used in the

production of new batteries to support the clean energy transition and reduce U.S. vulnerability to price shocks and volatility. This national supply, along with increased economies of scale and technological improvements, has the potential to result in the decreased cost of batteries.

### *Support the Development of a Domestic Lithium-ion Battery Supply Chain*

As the recycling industry grows, it could potentially lead to the development of a national battery supply chain and an enhanced closed-loop model. A closed-loop LIB supply chain consists of used batteries sent to recycling to recover materials, which are refined and returned to the battery supply chain to manufacture precursors and cathode materials. Finally, the cathode materials are used to manufacture batteries. Currently, there are no cathode manufacturers within the U.S., requiring recovered materials to be shipped internationally. The development of domestic recycling could encourage the development of an intermediary value chain industry within the U.S. In addition, increased recycling will inevitably lead to technological innovation within the industry that could result in higher efficiencies, thus minimizing residual waste. A similar effect may be observable for economies of scale and economies of learning, which could result in an economically sustainable industry.

## **6. POLICY PROPOSALS WITH MAJORITY SUPPORT**

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Based on the phase 2 outcomes documenting proposed policy options and their barriers and opportunities, a final list of proposed policy options was developed. Following this, a survey soliciting feedback on the proposed policy options was distributed to Advisory Group members. Members were asked to rate each policy option on a Likert scale (that is indicating their strong support, support, support with modification, no opinion, opposition, or strong opposition). This survey was used to focus discussion and solicit recommended changes to those policy proposals most likely to garner majority support from the Advisory Group during subsequent meetings.

On November 2, 2021, Advisory Group members were then asked to vote on each policy proposal. Members could either vote in favor, vote to oppose, abstain, or could recuse themselves from the vote. Members that were absent for the initial vote were asked to vote at the December 7, 2021 meeting. . The level of support was determined by dividing those in support by all voting members. If Advisory Group members elected to recuse themselves, they were not counted among voting members and thus were excluded from the calculation of percent support. Majority support is defined as any policy proposal for which the level of support exceeds 50%. In total, 15 Advisory Group members participated in the final vote; the full results can be found in table A2 of the appendix.

The four state agency representatives recused themselves from voting for all policy options. As representatives of individual agencies within the Executive Branch, rather than the full Administration, these agencies felt it was inappropriate to endorse a specific policy outcome or recommendation in a report to the Legislature. Rather, should any of these recommendations be discussed within the Legislature, the Administration would provide input in due course and through the appropriate channels.

## 6.1 POLICIES DEFINING RESPONSIBILITY FOR END-OF-LIFE MANAGEMENT

At present, no party is required to coordinate and pay for the collection, transportation, and processing of retired out-of-warranty batteries, so the pathway depends on the economic value and feasibility of reuse and/or recycling. This could create “stranded batteries” if individual consumers or small operations end up in possession of LIBs that they do not have the resources or motivation to dispose of properly. Without a mechanism to collect stranded batteries, they may be unsafely accumulated, illegally abandoned, or improperly managed domestically and abroad.

To avoid improper management, the following EOL management policy options were developed through subcommittee deliberation and Advisory Group discussion. These policies seek to ensure that all batteries are captured and properly reused, repurposed, or recycled by defining a responsible party at EOL (options 1, 2a, and 2b), or by establishing a financing mechanism to pay for EOL management (options 3, 4, and 5). As documented in the November 2<sup>nd</sup> and December 7<sup>th</sup> meeting, policy proposals 1 and 2a received majority support, while the others did not (see Table 8).

Regardless of which option is adopted by the legislature, the following aspects must be carefully considered:

- There should be a clear transfer of responsibility for EOL management when batteries are reused or repurposed. Responsibility includes re-labeling of batteries to identify the responsible party in the case of reuse or repurposing; arranging reverse logistics to transport batteries to recycling hubs; payment of recycling cost, if required; and documentation of recycling. How the responsible party should provide proof of proper reuse, repurposing, and/or recycling must be established.
- If responsibility for EOL management includes ensuring that batteries are properly recycled, it is necessary to define what constitutes “proper recycling”. This could mean requiring batteries be sent to a facility that is licensed to recycle batteries in the U.S., or to facilities that meet an international standard in terms of environmental performance and other metrics. There is currently no international standard, so the criteria and how it should be verified would need to be defined through a separate consensus-based process.

**Table 8.** Advisory Group vote outcomes and level of support for EOL management policy proposals.

<b>Policy proposal</b>	<b>In Favor</b>	<b>Opposed</b>	<b>Abstain</b>	<b>Level of support (%)</b>
1. Core exchange and vehicle backstop	14	0	1	93%
2a. Producer take-back	10	4	1	67%
2b. Producer take-back with companion legislation requiring return to OEM	4	10	1	27%
3. Environmental handling fee	6	7	2	40%
4. Environmental handling fee gathered through vehicle registration	5	7	3	33%
5. Hybrid environmental handling fee	5	9	1	33%

Sections 6.1.1 and 6.1.2 provide more detailed information for policy proposals 1 and 2a, the two that received majority support. For each of the proposals, the Advisory Group and UC Team provided advantages and disadvantages illustrating the complexity of each policy option. Proposals 2b-5, which did not receive majority support, are detailed in Section 7.1.

### ***6.1.1 Core Exchange and Vehicle Backstop Policy***

This policy is built upon existing industry standards and policies for other components, specifically a core exchange and product take-back. It is not intended to replace current warranty regulations or programs; if a battery is removed while under warranty, the vehicle manufacturer is responsible for properly reusing, repurposing, or recycling. The proposal defines responsibility for out-of-warranty batteries via three pathways:

- 1) For EVs **still in service**, if a battery pack, module, or cell is replaced before the vehicle reaches EOL, a core exchange program detailed by the EV battery supplier\* shall be used for the replacement battery (or any module or cell). The entity removing the battery shall be responsible for ensuring the used battery (or module or cell) is properly reused, repurposed, or recycled. The entity selling an EV battery shall use a core exchange\*\* program to track that the used battery has been properly managed.
- 2) For EVs **reaching EOL**, a dismantler who takes ownership of an EOL vehicle is responsible for ensuring the battery is properly reused, repurposed, refurbished, or recycled. If an EV battery is directly reused in another vehicle with no alterations, the process for EVs still in service shall apply. If the battery is refurbished or repurposed, the responsibility transfers to the refurbisher or repurposer.
- 3) In circumstances where an EOL EV with an OEM-certified battery is **not acquired and removed by a licensed dismantler**, the vehicle manufacturer shall be responsible for



ensuring that the vehicle is properly dismantled and the LIB is properly reused, refurbished, or recycled.

### *Definitions:*

\*Supplier refers to the entity selling the battery, which could be a manufacturer or refurbisher.

\*\*Core exchange: In the auto parts industry, a “core” is used to encourage the return of old parts that can be remanufactured or recycled. Often, this takes the form of a core charge, where the customer pays a deposit when purchasing a new part. The deposit is then refunded when the part is returned. In the vehicle backstop policy proposal, the details of the core exchange program can be decided by the vehicle OEMs or battery suppliers and may or may not involve an added charge. Two examples provided by the Alliance for Automotive Innovation were 1) a case where the used battery is shipped to vehicle OEM part sales, and 2) where the battery is replaced by a repair shop with an existing recycling arrangement:

- 1) The battery is removed by a repair shop, who ships it to vehicle OEM part sales, battery aftermarket sales, or a battery refurbisher. These entities return a replacement battery to the repair shop, and is then responsible for ensuring the used battery is properly recycled, refurbished, or sent for second-use.
- 2) The vehicle OEM, battery aftermarket sales, or battery refurbisher requires assurance that the repair shop removing the battery has properly recycled, refurbished, or put it into a non-vehicle secondary use market before providing a replacement battery.

### *Considerations for implementation*

- The legislature or responsible agency should revisit this policy periodically to assess its effectiveness in preventing stranded and exported batteries and evaluate whether any changes are necessary.

### *Advantages*

- The “vehicle backstop” will address LIBs that could potentially become stranded
- Depending on how the vehicle backstop is implemented, it may be the sole means of capturing batteries that are currently on the road and out of warranty.
- Does not add an upfront fee to the cost of the EV
- Encourages independent reuse and repurposing for batteries with available capacity
- Specifies transfer of responsibility for reused, refurbished, and repurposed batteries

### *Disadvantages*

- Potentially increased costs to the OEM under the assumption valuable LIBs at their EOL will be sold to a third party, and the OEM will be contacted to dispose LIBs with negative value
- Increased cost to the OEM could result in higher prices and negatively impact EV penetration
- If the OEM goes out of business this may result in orphaned batteries which do not have a party responsible for the EOL management

### **6.1.2 Producer Take-Back**

The auto manufacturer is responsible to ensure proper reuse, repurposing, or recycling of its EV traction batteries by a licensed facility at no cost to the consumer if and/or when they are no longer wanted by the owner, and in the event no other entity has taken possession of the battery. Auto manufacturer responsibility initiates when the auto manufacturer has been notified the battery has reached its EOL and is available to be reused, repurposed, or recycled. If the battery is repurposed, the EOL responsibility transfers to the repurposing company. This responsibility includes:

- Arranging reverse logistics to transport the batteries to recycling hubs
- Being responsible for the recycling costs
- Documenting the proper disposal of the battery

The Auto manufacturer will provide educational materials to customers and the service/repair industry, explaining the return process. This material will be made available through the vehicle owner manual or in-vehicle display, in printed dealer materials, and online.

### *Advantages*

- Clearly defines responsibility while providing the option for EV owners to sell the battery at the EOL or contact the vehicle OEM to correctly dispose of it
- The ability for batteries to be sold to a third party at the EOL provides opportunity for growth in the remanufacturing, refurbishing, and repurposing industry without requiring a partnership with the vehicle OEM
- Incentivizes design for recycling and disassembly

### *Disadvantages*

- Increases costs to the manufacturer under the assumption valuable LIBs at their EOL will be sold to a third party, and the vehicle OEM will be contacted to dispose LIBs with negative value

- Increased cost to manufacturer could result in higher prices and negatively impact EV penetration
- If the vehicle OEM goes out of business this may result in orphaned batteries which do not have a party responsible for the EOL management

## 6.2 SUPPORTING POLICY PROPOSALS

In addition to recommending a comprehensive policy defining responsibility at EOL, the subcommittees developed 19 policy options to address more specific barriers and opportunities in the following categories:

- Access to Battery Information
- Support Reuse, Repurposing, and Recycling Industry Development
- Reverse Logistics
- Circular Economy and Quality Recycling

**The proposed policy options are not mutually exclusive** and should be considered complementary to any potential policy that defines responsibility, such as those proposed in sections 7.1.1 and 7.1.2. In total, 12 of 19 proposed supporting policies garnered majority support according to the Advisory Group vote on December 7<sup>th</sup>. The remaining policies are presented in Section 6.2, and the detailed voting and survey outcomes are presented in Table A1 and A2 in the Appendix.

**Table 9.** Supporting policy proposals with majority Advisory Group support

Category	Policy	Purpose	Level of support (%)
Access to battery information	Physical labeling requirement	Facilitate sorting to improve process efficiency; enable easy identification of battery/vehicle OEM	93%
Access to battery information	Digital identifier	Identify LIB chemistry at EOL; identify responsible party for safe disposal; improve safety during disassembly	87%
Access to battery information	Universal diagnostic system	Reduce cost of testing; enable performance guarantees for reused and repurposed batteries	53%
Support repurposing, reuse, and	Recycling incentive packages	Mitigate upfront capital costs; encourage recycling within California	73%

<b>Category</b>	<b>Policy</b>	<b>Purpose</b>	<b>Level of support (%)</b>
recycling industry development			
Support repurposing, reuse, and recycling industry development	DTSC permit timeline	Reduce cost of locating processing facilities within California	60%
Support repurposing, reuse, and recycling industry development	Expand eligibility for battery storage systems	Enable cost-competitiveness with new batteries	67%
Safe and efficient reverse logistics	Support enforcement of unlicensed dismantling laws	Prevent environmental hazards and stranded batteries due to unlicensed dismantling	87%
Safe and efficient reverse logistics	Develop training materials	Improve safety and workforce capacity	93%
Safe and efficient reverse logistics	Support transportation research	Reduce transportation cost	100%
Safe and efficient reverse logistics	Develop strategic collection and sorting infrastructure	Reduce transportation cost	93%
Safe and efficient reverse logistics	Universal waste regulations	Reduce transportation cost and administrative burden	100%
Safe and efficient reverse logistics	Require pre-approval to bid on EVs at auctions	Enable tracking of EVs purchased at auctions	60%

**6.2.1 Access to Battery Information**

Lack of access to information about battery packs was identified as a barrier by all subcommittees. The party removing the battery needs information about the condition to determine the next suitable use and whether any extra precautions are necessary during shipping and handling. In addition, the reuse, refurbishing, or repurposing company needs information about the battery’s SOH to ensure quality and provide performance guarantees, and recyclers need to know the chemistry to sort batteries and process them at maximum efficiency. The following policies are recommended by the Advisory Group to increase access to information:

### *Physical labeling requirement*

Require OEMs to attach a standardized physical label containing information about the battery in symbol or text form to the pack in a visible and legible manner. The label(s) should be located such that they are visible during maintenance, replacement and after being removed from the vehicle.

The California Air Resource Board (CARB) is developing a labeling requirement as part of their proposed Advanced Clean Cars II regulation.<sup>97</sup> The information required includes the manufacturer name, cathode chemistry, voltage, performance/capacity, product alert statements/hazards, composition/process related information, and electronic information exchange/digital identifier. Advisory group members recommend that labeling requirements align with the forthcoming CARB standard, as well as the Society for Automotive Engineers standard for EV batteries (SAE2936).<sup>98</sup>

### **Advantages**

- The label allows recyclers to easily sort LIBs by cathode chemistry, which maximizes process efficiency and material recovery rates and avoids complications
- Easy identification of the vehicle OEM and chemistry will streamline the repurposing process since most stationary repurposed systems are built using the same type of battery. Because some cathode chemistries have more material recovery value than others, information about battery chemistry will enable the party handling the battery to negotiate the cost paid to or by recyclers.

### **Disadvantages**

- If only elements present in the cathode are listed and not the full stoichiometry of the cathode (e.g., NMC 622) or the composition of the rest of the battery, it may not be enough to identify the value of materials within the battery
- The cathode chemistry may be proprietary information to the battery manufacturer
- If the vehicle OEMs delegate the labeling responsibility to the auto dealers, this could be overly burdensome to the dealerships
- Applying this label to the pack only may lead to information loss if the modules or cells are separated

### *Electronic Information Exchange (i.e., a QR code linking to online database)*

An electronic information exchange should be enabled by a digital identifier, such as a QR or barcode, applied as a physical label on the battery pack. This digital identifier will direct to an online database.

The Advisory Group recommends the following information to be included in the online database:

- Main cathode chemistry (e.g. NMC)
- Capacity (e.g. 100 kWh)
- System voltage (e.g. 28.8V)
- Instructions for disassembly from the vehicle
- Vehicle OEM contact information to request safe disposal of the battery

### ***Advantages***

- Providing easily accessible disassembly instructions can increase safety at battery EOL
- Easily accessible vehicle OEM contact information can expedite the recovery of LIBs at their EOL, which would prevent stranded batteries and increase recycling rates
- The information shared on this platform has the potential to expand past the Advisory Group recommendations

### ***Disadvantages***

- May not be enough information to maximize reuse, repurposing, and recycling
- Applying this QR code to the pack only may lead to information loss if the modules or cells are separated

### ***Universal diagnostic system***

In addition to information about the contents of the battery pack, enabling third-party access to state-of-health (SOH) information could facilitate repurposing and reuse by reducing the time required for testing. A Universal Diagnostic System (UDS) installed on the battery would enable non-OEM actors to access relevant data about the condition and/or history of the battery *after it has been removed* from the vehicle. The UDS would be analogous to the Onboard Diagnostics II (OBD2) systems in vehicles where engine and other vehicle system information (and particularly faults or failures) is reported. OBD2 is required for all light-duty vehicles built after 1996.

The California Air Resources Board is currently drafting a standardized battery SOH proposal as part of the Advanced Clean Cars II regulation. CARB's proposal requires the OEM to calculate a SOH of battery with a minimum accuracy (+/- 5%) based on the remaining amount of 'Usable Battery Energy' as measured by SAE J1634 lab test methods. The SOH must be readable by a driver without a tool and normalized so that 100% equals new on all cars. The proposal also requires OEMs to define and disclose the SOH value that qualifies for warranty repair.

The CARB proposal is distinct from this proposal for a UDS because the UDS would function even after a battery is removed from a vehicle; however, coordination and alignment with CARB where possible is recommended to avoid overlapping regulation.

### ***Advantages***

- Enables informed decisions about reusing, repurposing, and recycling, which ultimately reduces the overall costs
- Increased information on the use and SOH can enable maximum use and value out of the battery packs through repurposing and reuse
- May keep an EV on the road for a longer period of time before owners must purchase a new vehicle, reducing costs to vehicle owners.
- Enables more locations to diagnose and work on batteries, which would lower cost to consumers

### ***Disadvantages***

- Could require special LIB design for vehicles sold in California and result in increased costs
- Intellectual property concerns for OEM and battery supplier algorithm and software
- Easily accessible information on state of health could encourage unlicensed repurposing

## ***6.2.2 Support Reuse, Repurposing, and Recycling Industry Development***

The high upfront cost and lack of large-scale battery retirement contribute to the challenging economics of reuse, refurbishing, and repurposing. Furthermore, it is preferable for disassembly, reuse, and recycling to take place within California to create skilled jobs and guarantee the processes meet the state's high environmental standards; however, these standards may also add cost, making it difficult to compete with other jurisdictions. The following policies are recommended by the Advisory Group to mitigate these barriers and encourage industry development within California

### ***Economic incentive package provided to lithium-ion battery recyclers within California***

The State should provide financial incentives in the forms of tax breaks or grants to hazardous waste processors that recycle LIBs to mitigate upfront costs and encourage industry development within California.

### ***Advantages***

- Subsidizing upfront costs will make California-based recycling competitive with other states

- Recycling within California will ensure compliance with high environmental standards and reduce the transportation distance at the EOL

### ***Disadvantages***

- Does not ensure the long-term economics are profitable
- Could lead to overbuilding recycling capacity or inefficient siting
- The public may be skeptical about recycling as a hazardous waste processing industry

### ***Establish a timeline for hazardous waste processing permit***

As part of the hazardous waste facility permitting process, a timeline shall be established during the initiation of the permitting process. Both DTSC and the permit applicant are expected to comply with this timeline and any and all milestones as described in Senate Bill 158.<sup>99</sup> The successful completion of this process in a timely manner depends on the applicant providing adequate revisions of permit applications to DTSC in a timely manner. Permit applicants must provide adequate and timely responses to identified deficiencies in the application.

### ***Advantages***

- Addresses the lengthy and uncertain permitting process in California compared to other states, which was identified as a barrier to the recycling industry
- Provides transparency and certainty
- Could lead to the establishment of a recycling facility in California, thus creating skilled labor jobs and reducing the cost and emissions of the LIB EOL by reducing transportation distance to the recycling facility

### ***Disadvantages***

- If DTSC's budget is cut or they are not able to keep up with applications, application approval may be rushed and there is a risk that mistakes or flaws will be overlooked
- A process is needed to weed out frivolous applications and avoid the involvement of bad actors

### ***Expand eligibility for relevant incentive programs to include reused and repurposed batteries***

Currently, repurposed battery storage systems are not eligible for existing incentive programs that subsidize the cost of new battery storage. The Advisory Group recommends encouraging the CPUC Program Administrator to consider expanding eligibility for the self-generation incentive program (SGIP), provided repurposed batteries meet specified performance and



warranty criteria. The performance standards should be developed based on the best available research on safety, SOH, and battery lifetime.

In addition, the Advisory Group recommends that responsibility for EOL management, including recycling and labeling, be required for all suppliers that participate in incentive programs for stationary batteries.

### ***Advantages***

- Enables repurposed batteries to compete with new batteries

### ***Disadvantages***

- Further research is needed on the performance and safety of repurposed batteries

## ***6.2.3 Reverse Logistics***

The Advisory Group recommends the following policies to support the safe and efficient removal, handling, and transportation of EOL batteries.

### ***Support enforcement of unlicensed dismantling laws***

An ongoing concern in the state of California is the rise of unlicensed dismantling, which is problematic because unlicensed dismantlers do not take the same precautions when disposing of hazardous materials and fluids. Unlicensed dismantling is particularly undesirable for EVs given the hazards posed by large-format LIBs when handled incorrectly. Increased resources should be provided to improve enforcement of unlicensed dismantling laws, for example through the existing Vehicle Dismantling Industry Strike Team which is led by the Department of Motor Vehicles (DMV).

### ***Advantages***

- Support businesses that operate safely and environmentally responsibly
- Improve the business environment for the licensed auto dismantling industry

### ***Disadvantages***

- Added enforcement creates an administrative burden for the DMV

### ***Develop Training Materials for Parties Handling EOL Batteries***

To support industries that will need to adapt to vehicle electrification and promote safe EOL management, funding should be made available to support training materials that provide

clear, detailed guidelines on occupational safety, storage, and shipping protocol and requirements. Examples of current efforts to increase training include a course for first responders created by the National Fire Protection Association, and a webinar on the safe handling of LIBs (mainly portable) created in a joint effort by the U.S. Department of Transportation (USDOT) and the EPA.

### ***Advantages***

- Develop workforce capacity and promote safety

### ***Disadvantages***

- None to report

### ***Universal Waste Regulation***

LIBs at their EOL are classified by DTSC as a universal waste and meet the definition of hazardous waste under RCRA due to their risk of ignitability and toxicity. A key point of discussion for all subcommittees was defining at what point they become waste, which will affect what activities are considered hazardous waste treatment and who is considered a generator, handler, or treatment facility. It was suggested that batteries be considered waste *only after it has been demonstrated they do not have sufficient remaining capacity for reuse or repurposing*. However, such changes would need to be adopted at a federal level before it could be implemented by DTSC.

The Advisory Group recommends that if the U.S. EPA changes the status of retired batteries in a way that reduces regulatory burden, DTSC should evaluate those changes and adopt them as long as they are consistent with the continued protection of public health and the environment in California.

### ***Advantages***

- Reduces unnecessary administrative burden and provides clarity for parties handling EOL batteries

### ***Disadvantages***

- Reducing regulatory burden must be limited to actions that do not sacrifice safety, public health, or environmental stewardship

### *Identify Strategies to Reduce the Burden of Transportation*

The Advisory Group recommends the state support research on solutions to reduce the cost of collection and transportation. This research should include 1) technical solutions for regulatory compliance related to packaging and handling safety mechanisms, and 2) regulatory analysis focused on lowering the costs of federal regulation compliance without compromising safety. There is greater support among the Advisory Group for research focused on technical solutions related to packaging and handling than regulatory analysis on lowering the costs of compliance.

#### ***Advantages***

- Shipping and handling costs are significant and lowering these costs without compromising safety will improve the overall economics of repair services, as well as reuse, repurposing, and recycling

#### ***Disadvantages***

- Lowering the cost of compliance must not sacrifice safety
- Research will cost money

### *Develop Strategic Collection and Sorting Infrastructure*

To support a more efficient reverse logistics network, the state should support the development of strategically located collection and sorting facilities. State support constitutes assisting with site selection, permits, land use, etc., and not the construction of infrastructure.

#### ***Advantages***

- A spatially optimized collection network will reduce the transportation distance at EOL, which will make the system more efficient and reduce cost and environmental impact

#### ***Disadvantages***

- State involvement could lead to unnecessarily high oversight costs and/or a less efficient system compared to allowing the marketplace to determine collection and sorting infrastructure

### *Require Pre-Approval to Bid on Electric Vehicles at Auctions*

Unlicensed dismantlers acquire most of their vehicles through auto auctions. To minimize unlicensed dismantling, the Advisory Group recommends requiring that interested parties apply for pre-approval before participating. The pre-approval process should include registering and verifying contact information (e.g. name, address, etc.) in order to track the battery.

The logistics subcommittee also discussed including a safety training requirement, but ultimately decided this was outside the scope of the Advisory Group. Members noted that this policy should be implemented in a way that minimizes administrative burden for parties who are qualified to work on EVs.

***Advantages***

- Discourages illegal dismantling and unsafe DIY repurposing

***Disadvantages***

- Many individuals participate in insurance auctions to repair their own vehicles, not as unlicensed dismantlers. Several Advisory Group members as well as members of the public commented that this should be enforced in a way that allows this practice to continue
- Further research on implementation is needed

## 7. POLICY PROPOSALS WITH LESS-THAN-MAJORITY SUPPORT

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The following policy options are worthy of consideration by the legislature but did not receive majority support from the Advisory Group vote.

### 7.1 ALTERNATIVE PROPOSALS TO DEFINE END-OF-LIFE MANAGEMENT

#### 7.1.1 *Allocating Responsibility*

##### *Producer Take-Back with Companion Legislation Requiring Return of the Lithium-ion Battery to the Original Equipment Manufacturer at End-of-Life*

The auto manufacturer is responsible to ensure proper reuse, repurposing, or recycling of its EV traction batteries by a licensed facility. Auto manufacturer responsibility initiates when the auto manufacturer or its agent takes custody of the battery at no cost to the consumer. This responsibility includes:

- Arranging reverse logistics to transport the batteries to recycling hubs
- Being responsible for the recycling costs
- Documenting the proper disposal of the battery

The Auto manufacturer will provide educational materials to customers and the service/repair industry, explaining the return process. This material will be made available through the vehicle owner's manual or in-vehicle display, in printed dealer materials, and online. *In addition, companion legislation that requires all EV batteries to be returned to the manufacturer or its agent upon removal from the EV is necessary.*

#### **Advantages**

- Clearly defines responsibility at the EOL
- Provides the vehicle OEM with a stream of used LIBs that will likely be valuable

#### **Disadvantages**

- Considering the return of LIBs to the vehicle OEM at their EOL would be required, this policy deters from reuse or repurposing through a third party that does not have a partnership with the vehicle OEM

### **7.1.2 Environmental Handling Fees**

#### *Environmental handling fee applied at time of purchase*

A one-time payment is assessed at the point of purchase of a new EV to finance an EOL collection and recycling program. Further research should be done to estimate the appropriate fee and fee structure (e.g., based on the size of battery or type of car). The fee should be reevaluated and adjusted yearly. These are dedicated funds for managing EOL batteries and should be preserved for this use.

#### **Advantages**

- Establishes a fund to cover EOL costs for all LIBs, including stranded batteries

#### **Disadvantages**

- Increases upfront acquisition cost of EVs
- Considering the EV will retire on average in 10+ years, it is difficult to determine an accurate fee level to cover the cost of future recycling

#### *Environmental Handling Fee Gathered Through Vehicle Registration Fee*

A recurring fee is gathered at the time of yearly vehicle registration to finance a LIB collection and recycling program. Further research should be done to estimate the appropriate fee and fee structure (e.g. based on the size of battery or type of car). The fee should be reevaluated and adjusted yearly. These are dedicated funds for managing EOL batteries and should be preserved for this use.

#### **Advantages**

- Establishes a fund to cover EOL costs for all LIBs, including stranded batteries and those purchased outside of California
- Reduces upfront acquisition cost to EVs
- The cost can be adjusted yearly based on the cost of recycling
- Burden is shared by all owners over the EV lifespan

#### **Disadvantages**

- Registration fees will be higher for EVs than internal combustion engine cars
- Increases ownership costs of EVs which would negatively impact EV adoption and state pollution and climate goals
- Total fee paid is dependent on the LIB lifespan

### *Hybrid Environmental Handling Fee*

A recurring fee is gathered at the time of vehicle registration to finance a LIB collection and recycling program. This yearly fee will be split between the EV owner and the auto manufacturer. Further research should be done to estimate the appropriate fee and fee structure (e.g. based on the size of battery or type of car). The fee should be reevaluated and adjusted yearly. These are dedicated funds for managing EOL batteries and should be preserved for this use.

#### ***Advantages***

- Establishes a fund to cover EOL costs for all LIBs, including stranded batteries and those purchased outside of California
- Shares costs between EV owners and the vehicle OEM
- Could avoid large upfront acquisition cost to EVs
- The cost can be adjusted yearly based on the cost of recycling
- Burden is shared by all owners over the EV lifespan

#### ***Disadvantages***

- Registration fees will be higher for EVs than internal combustion engine cars
- Potentially increases the acquisition cost of EVs
- Total fee paid is dependent on the LIB lifespan

#### ***Additional commentary***

If a fund were to be established through an environmental handling fee, the majority of the Advisory Group recommended it be managed by a third party and not a state agency.

## **7.2 SUPPORTING POLICY OPTIONS WITHOUT MAJORITY SUPPORT**

This section presents the policies that did not receive support by the Advisory Group during the vote on November 2<sup>nd</sup> and December 7<sup>th</sup> but may still be worthy of consideration by the legislature. Some of these policies did receive support during the initial survey, which will be noted and further discussed in the policy subsections.

**Table 10.** Additional supporting policies that are not recommended because they did not have majority support during the Advisory Group vote. An asterisk next to the policy indicates the policy received majority support in the survey, but not in vote.

<b>Category</b>	<b>Policy</b>	<b>Purpose</b>	<b>Level of support (%)</b>
Support industry development	Disassembly incentive packages*	Encourage disassembly within California	20%
Circular economy and quality recycling	Recycled content standards	Create demand for recycled material; improve sustainability of new EVs	47%
Circular economy and quality recycling	Minimum material recovery targets*	Ensure recovery of critical materials	47%
Circular economy and quality recycling	Third-party verification	Ensure batteries are recycled sustainably	40%
Circular economy and quality recycling	Require design for reuse and recycling*	Reduce reuse and recycling cost	33%
Circular economy and quality recycling	Reporting system for EV batteries retired from use	Improve access to information about location of LIBs at EOL	33%
Circular economy and quality recycling	Reporting system for LIB recycling and recovery rates	Improve access to information about recycling rate of LIBs	33%

***Support Reuse, Repurposing, and Recycling Industry Development***

*Economic Incentive Package to Encourage Disassembly Within California*

Provide financial incentives in the forms of tax breaks or grants to facilities who disassemble battery packs to encourage industry development within California.

***Comparison of voting and survey outcomes***

While a majority of the Advisory Group did not support this policy in the vote, the survey resulted in support by a slim majority of 55%, with 30% of the members expressing no opinion.

***Advantages***

- A disassembly industry will create skilled jobs in California



### ***Disadvantages***

- Concern that bad actors could take advantage of financial incentives, leading to abandoned sites
- Encourages disassembly within California regardless of whether it is the optimal location

### ***7.2.2 Circular Economy and Quality Recycling***

The following policies were intended to promote circular economy principles, reduce the processing cost of reuse and recycling, and ensure that batteries are recycled using sustainable processes that recover critical materials.

#### ***Minimum Material Recovery Rates***

Required recovery rates for specific materials have been proposed in the EU to guarantee that critical materials are recovered. The “recovery rate” is the output of a specific material in usable form as a percentage of total input of that material.

Further research is needed to identify feasible target rates, which materials should be included, and the best process for implementation to ensure that domestic and international recyclers are on an even playing field. The targets should be phased in over time and reflect technological developments and commercial recycling capability in North America. An example of target recovery rates for LIBs is the proposed "medium ambition" revisions to the EU Battery Directive that specify the following material recovery rates in 2025. Please note these rates are an example and not the recommended rates by the Advisory Group.

- Cobalt: 90%
- Nickel: 90%
- Lithium: 35%
- Copper: 90%

#### ***Comparison of voting and survey outcomes***

The survey resulted in support of this policy, although by a slim majority of 55%, with 10% of the members expressing no opinion.

### ***Advantages***

- Requires recycling processes with a high yield rate
- Provides a method for targeting the recovery of critical materials
- Allows for flexibility and the increasing of targets as recycling technology matures

### ***Disadvantages***

- The rates established for the purposes of critical material recovery and sustainability may not be profit-maximizing for the recycling industry
- Global consistency of definition and calculation process of materials recovery may be difficult to achieve causing incorrect recovery rate achievement

### ***Design for Repurposing, Reuse, and Recycling***

Disassembly at EOL is time- and cost-intensive for repurposers and recyclers. Requiring or incentivizing OEMS to design batteries in a way that facilitates repurposing, reuse, and recycling could make disassembly at EOL less time-and cost-intensive for repurposers. Examples of design for reuse or recycling that are not binding or exhaustive include sealing battery packs with screws instead of adhesives, using an alternative binder than polyvinylidene fluoride to increase EOL solubility, and converting to solid busbars that are in a standardized position.

### ***Comparison of voting and survey outcomes***

The survey resulted in support of this policy, with a slim 55% majority in support, 5% of the members responding support with modifications and 15% of the members expressing no opinion.

### ***Advantages***

- Increasing the efficiency of repurposing, reusing, and recycling of LIBS at the EOL will decrease EOL processing costs
- Can increase the safety of disassembling LIBS at their EOL
- Encouraging consideration of EOL during the design process promotes circular economy principles

### ***Disadvantages***

- Imposing strict prescriptions for product design has the potential to hamper innovation. There are potential tradeoffs between designing for their EOL and other key aspects for their first use such as safety, cost, and performance
- Could increase manufacturing costs

### ***Third-Party Verification***

LIBs should be disassembled, processed, and recycled in facilities that have been verified by a third party to guarantee high-quality environmental performance (i.e. emissions control) and

worker safety. This is intended to provide assurance that recycling facilities operating in any jurisdiction outside California are conforming to a minimum standard.

The Advisory Group recommends the legislature call for the establishment of a process standard for facilities where used LIBs, production scrap, and derived materials are processed or recycled. This will require consensus standard development to address specific types of processes within recycling and processing facilities (e.g. dismantling, pyrometallurgical, hydrometallurgical). The process standard would then be approved by a designated state agency and verified by a third party through an initial and annual auditing process.

The third party should be an independent source (e.g. certification body) that awards certification based on a facility meeting certain environmental criteria outlined in a certification standard and described in certification requirements. Examples of programs using third-party verification include E-stewards and PaintCare.

### ***Comparison of voting and survey outcomes***

The survey also did not show majority support of this policy, with only 45% in support, although the majority was close with 5% of members willing to support with modification. In addition, 30% responded with no opinion.

### ***Advantages***

- Discourages export of LIBs to facilities that do not meet environmental standards
- Supports a level playing field for recyclers

### ***Disadvantages***

- Cost of oversight and administration could increase the cost of recycling

### ***Recycled Content Standards***

Mandatory recycled content standards were suggested to ensure the use of recycled materials in battery manufacturing. “Recycled content” refers to the total percentage of recovered material used to manufacture a new product. The recycled content standard would be third-party verified by an independent source (e.g. certification body) that awards certification based on the product and facility meeting certain environmental criteria outlined in a certification standard and described in certification requirements. This requires consensus standard development to address specific types of processes within the manufacturing.

As an example, proposed revisions to the EU Battery Directive include the following minimum recycled content standards. Please note these rates have not been recommended by the subcommittee:

- January, 2030: 12% cobalt; 4% lithium; 4% nickel
- January, 2035: 20% cobalt; 10% lithium; 12% nickel

Further research is needed to determine achievable recycled content standards and analyze the economic impacts. These rates should be phased-in and reviewed/ revised to account for technical developments.

### ***Comparison of voting and survey outcomes***

Recycled content standards only received 25% support in the survey, although an additional 25% supported with modifications. The modifications were mainly expressing the need for further research. The policy was opposed by 40% of members.

### ***Advantages***

- Can drive a robust recycling industry by creating demand for recycled material, particularly given the size of the EV market in California
- Reduce the environmental impact of producing new EVs

### ***Disadvantages***

- Manufacturing new LIBs may not be the most economical use of recovered material. As an alternative, one Advisory Group member suggested requiring minimal recovery of battery grade materials (materials refined to a sufficient quality to manufacture LIBs) without specifying the end use
- Difficult to verify
- Could artificially inflate the value of battery materials and increase cost of manufacturing, and, ultimately, the cost of EVs

### ***Develop a Reporting System for EV Batteries Retired from Use***

The ability to track EV batteries will enable policymakers and researchers to evaluate the effectiveness of recycling policies and identify sources of leakage from the EOL system, particularly vehicle or battery exports. An online database should be created to track and report LIBs that are retired within California and used EVs that are exported from California. Companies recycling or repurposing EV batteries within California, and companies moving EV batteries from California for this purpose, are responsible for reporting the final recipients of the batteries.

Reporting retired batteries and their recipients could be facilitated with a digital identifier, aligning with traceability programs proposed by the Global Battery Alliance.

### ***Comparison of voting and survey outcomes***

This policy was supported by 45% of Advisory Group members in the survey, with an additional 5% selecting support with modifications. It was opposed by 45%, with only 5% expressing no opinion.

#### ***Advantages***

- Increases transparency along value chain
- Facilitates evaluation and improvement of recycling policies

#### ***Disadvantages***

- Hazardous waste processors already have to comply with reporting requirements
- Further research on implementation and enforcement is needed
- Creates administrative costs for government agencies to managing database and reporting requirements for industry
- Should be included as part of a comprehensive EOL strategy and not as a standalone policy

### ***Develop a Reporting System for Lithium-ion Battery Recycling Recovery Rates***

An online database should be created to track and report LIB recycling recovery rates. Companies recycling batteries are responsible for reporting their total recovery rates, as well as the recovery rates of cobalt, lithium, manganese, and nickel.

### ***Comparison of voting and survey outcomes***

This policy was supported by 30% of Advisory Group members in the survey, with an additional 15% selecting support with modifications. It was opposed by 40%. The remaining 15% expressed no opinion.

#### ***Advantages***

- Increased knowledge of industrial recycling capabilities
- Provides empirical data to forecast circularity potential and material forecasting

#### ***Disadvantages***

- Additional database for government agencies to manage
- Additional reporting required of LIB recyclers

## 8. AREAS OF FUTURE RESEARCH

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The LIB recycling and reuse industry is evolving in preparation for the influx of EV LIBs that will reach EOL in the coming years. The development of the industry will determine the environmentally and economically preferable EOL management strategy, and the best policy mechanisms to encourage these circular economy practices. Many of the policies recommended by the advisory group require future research and should be updated as the industry evolves. In addition, there were several policies discussed, and not recommended, largely due to unknown impacts to the nascent industry and the international market. Below, in no particular order, are several areas the Advisory Group recommends for further research.

- **Solutions to reduce the cost of collection and transportation:** Similar to the policy recommendation in section 6.2.3, Identify Strategies to Reduce the Burden of Transportation, research on the technical and regulatory solutions to decreasing the cost of transporting EOL LIBs is recommended. The cost of transporting LIBs at their EOL is a substantial portion of recycling costs, estimated to represent between 40-60%; as such, reducing transportation costs can significantly decrease the cost of EOL management.<sup>33</sup>
- **Recycling performance targets:** Performance target policies, such as minimum material recovery rates, maximum process emissions, or third-party verification, were not recommended by the Advisory Group. Hesitancy about these policies usually centered around the need for more information about the impact on domestic and international recyclers, and ensuring they are on an even playing field. In order to address this uncertainty, research on appropriate emission levels, material recovery rates, the process for implementation, and the impact on the global market is needed.
- **Feasible recycled content standards and analysis of the economic impacts:** Research is needed to determine the level of recycled content that can be met with retired materials and the impact to the U.S. and international LIB market.
- **Reevaluation of safety aspects if/as chemistry changes:** The materials used in LIBs, specifically the cathode, anode, and the electrolyte, are continuing to evolve to. As the materials used change, the material interactions present different safety hazards, and the impact to the safety of recycling and reuse must continually be evaluated.
- **More data on the performance and safety of repurposed batteries:** Since the repurposing of batteries is fairly new, the performance (i.e. lifespan, degradation rate) and safety is unclear. In order to increase the public confidence and ensure this is the best use of materials, more research should be conducted. The CEC is currently supporting demonstration projects for this purpose (see section 2.2.).

- **Utilization and application of second-life in reducing the life cycle environmental impact:** Research of the life cycle impact of repurposing LIBs, and the impact of the application the stationary storage battery is used in on those life cycle impacts.

## 9. CONCLUSION

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Decarbonizing transportation is a cornerstone of California’s strategy to mitigate climate change. At the same time, transitioning away from internal combustion engines to battery-powered ZEVs requires a significant increase in demand for LIBs, whose life cycle includes a suite of environmental impacts from mining, refining, manufacturing, and disposal. The safe and environmentally responsible management of EV LIBs at EOL is therefore essential to achieving the State’s climate goals sustainably and equitably. Reusing batteries at vehicle EOL extends their usable life, potentially reducing the need for new batteries. Repurposing batteries for stationary storage may further support the State’s grid decarbonization goals by providing an affordable form of energy storage. Ultimately, recycling will be necessary to avoid unsafe final disposition and to recover critical materials for use in new LIBs or other products. Recycling that takes place regionally (i.e., within California or neighboring states) can best ensure processes meet a high standard for environmental performance and worker safety, reduce unnecessary cost and environmental impacts from transportation, and increase supply chain resilience by maintaining control of critical materials.

As a State with ambitious climate policies and the largest automotive market in the U.S., California is uniquely positioned to influence the sustainability of the EV value chain through leadership and proactive legislation. To assist the legislature in developing effective policy, this report outlines the existing landscape for reuse and recycling, summarizes key barriers that currently inhibit reuse and recycling according to a variety of stakeholders, and identifies some opportunities and benefits that could be realized through creating robust EOL programs and industries. Finally, we present a list of potential policies that support the goal of ensuring that as close to 100% of LIBs are properly reused, repurposed, or recycled at EOL and identify areas where further research is needed. This report does *not* do the following:

- Provide detailed guidance for implementation or enforcement
- Provide a specific definition for what constitutes “proper reuse or recycling” or how it should be verified.

The fundamental approach of the policies in this report is to 1) clearly define responsibility for the coordination and payment of recycling in cases where the cost presents a burden for the owner of the vehicle and the LIB is unwanted, and 2) mitigate barriers that add cost and inhibit the reuse and recycling of EV LIBs. Some of the key barriers addressed include capturing out-of-warranty batteries, the lack of access to important battery information, the burden of storing and transporting LIBs, uncertainty regarding the cost and performance of repurposed batteries,

and the complexity of navigating universal and hazardous waste regulations. In recommending policies, the Advisory Group sought to understand and support the systems that already handle EOL vehicles, including the existing auto dismantling, LIB repurposing, and LIB recycling industries.

The most widely supported policy defining responsibility for EOL management was the core exchange and vehicle backstop proposal, which allocates responsibility under three possible retirement pathways. The majority of the Advisory Group also supported a producer take-back policy making the vehicle OEM or repurposer responsible for ensuring proper reuse, repurposing, or recycling at a licensed facility and at no cost to the consumer. Under either policy, there should be a clear transfer of responsibility for EOL management when batteries are refurbished or repurposed. Both policies also require further consideration to define what constitutes “proper recycling” and how it should be verified.

Widely supported policies that address more specific barriers include labeling and digital identifier requirements, supporting the development of recycling facilities through incentive packages and a guaranteed permitting timeline, supporting the enforcement of unlicensed dismantling laws, and supporting the development of strategic collection and sorting infrastructure to reduce transportation costs. The Advisory Group also recommended training programs to ensure that the people who handle EOL vehicles have the skills they need to safely work with EVs and assist them in navigating regulatory requirements.

There are several areas where the Advisory Group recommends further research to understand the industry as it develops, rather than proposing binding policies. This represents a departure from EOL LIB policies from other regions, such as the EU’s proposed Battery Regulation, which sets specific targets and mandated requirements for recycling of batteries, collection rates, recycling recovery rates, and even recycled content standards. The Advisory Group considered, but ultimately did not recommend, several policies that were proposed by the EU; specifically, material recovery rates and recycled content requirements. While nearly half of the Advisory Group did support these policies as a means of ensuring that critical materials are recovered and used in battery production, others felt that they were too prescriptive and instead recommended establishing aspirational targets. Those who opposed these policies by and large believed that recycled content and material recovery rates provide valuable guidelines and goals for industry development, but more research is required to identify feasible targets and understand their economic impact.

This report also differs in scope compared to the proposed EU Battery Regulation, as it only addresses EOL LIBs from passenger EVs and therefore only applies to a subset of issues related to LIBs. This report intentionally does not address LIBs from heavy-duty vehicles, micro-mobility, or stationary storage because the Advisory Group convened by AB 2832 is specific to car batteries. The use of LIBs in these other applications, specifically large-format batteries for



grid support, will increase as efforts to decarbonize continue. While many of the policies may indirectly support the reuse and recycling of these batteries through supporting the industry in general, it is necessary to have consistent EOL policy for LIBs used in all applications.

In addition, while policies in the two largest EV markets, the EU and China, have developed strategic plans encompassing the entire battery life cycle, this report does not include recommendations targeted to other activities in the value chain. Nonetheless, the importance of more localized refining and cathode manufacturing capacity was emphasized throughout this process, and the interconnection between recycling, refining, and manufacturing is something the legislature should be aware of when drafting legislation.

To that end, the legislature should understand the contents of this report in the context of several other aligning efforts taking place at a state, federal, and international level:

- The CEC's ongoing support for repurposing demonstrations will provide better data around the performance and durability of second-life batteries, which will enable more informed policy decisions regarding incentives<sup>45</sup>
- The ongoing work of the Lithium Valley Commission in exploring the opportunities of developing a local supply hub for EV LIBs and potential impact to the local community<sup>32</sup>
- CARB's Advanced Clean Cars II Act, which is expected to include standards for labeling, SOH determination, and performance and durability requirements<sup>97</sup>
- Support for supply chain resilience, vehicle electrification, and recycling in the Biden Administration's Building Back Better agenda, including allocating \$6 billion for investment in the battery supply chain in the Infrastructure Investment and Jobs Act<sup>100</sup>
- Ongoing reuse and recycling projects supported by the Department of Energy's Lithium-ion Battery Recycling Prize<sup>101</sup>
- Internationally, the efforts of the Global Battery Alliance to increase the transparency and sustainability of the LIB value chain.<sup>76</sup>

Throughout the process, the Advisory Group members and invited speakers emphasized that EVs are a relatively new technology and are not yet being retired in California at a large scale. Understanding, therefore, that reuse, repurposing, and recycling are still nascent industries, it is important to emphasize that the landscape for EV EOL management is rapidly evolving, and policymaking aimed at supporting reuse, repurposing, and recycling should be iterative. Alternative technologies that reduce the need for critical materials may be developed, however the goals and intentions of reuse, repurposing and recycling in this report shall apply to all types of EV batteries. The recommendations included in this report should be revisited periodically to assess their effectiveness and evaluate whether any changes are necessary.

## 10. TERMINOLOGY

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**Anode** – A terminal which the current flows towards or the negative charge moves from during discharge in a battery. The material composition of an anode is typically some porous form of carbon and may fluctuate from battery to battery.

**Battery Electric Vehicle (EV)** – A motor vehicle that relies on an electric motor and battery system for primary tractive power.

**Battery Management System (BMS)** – An electronic system that manages operational components of a rechargeable battery. This could mean managing depth of discharge, tracking usage, controlling the environment and other aspects of the operation.

**Cathode** – A terminal which the current flows from or the positive charge moves from during discharge in a battery. The energy density of a battery is typically determined by the material of the cathode; thus, the typology of Li-ion batteries refers to the cathode chemistry.

**Collection rate** -- Proportion of EOL products that are collected and enter the recycling chain

**Direct cathode recycling**-- Also referred to as refunctionalization. A recycling method where cathode materials are recovered as a pure compound that can be directly used as an input into battery manufacturing, avoiding the need for refining of materials and resynthesis of cathode compounds.

**End-of-life recycling rate** -- Proportion of all EOL product material that is recovered by recycling; dependent on both process efficiency and collection rate.

**Gigawatt hour (GWh)** – A unit of energy. 1 GWh is equivalent to the energy consumption of 32,800 houses for one day (2018, USA average household).

**Hydrometallurgical**-- Chemical treatment of a material to separate it into constituent materials.

**Lithium-ion Battery (LIB)** – A battery with a cathode containing lithium. Generally, these batteries are known for being lightweight and energy-dense.

**Pyrometallurgical**-- Thermal treatment of a material to separate it into constituent materials, requiring heating above the melting point of the material.

**Recovery rate/process efficiency rate** -- The output of a specific material in usable form as a percentage of total input of that material

**Recycled content** -- Fraction of a product's manufacturing inputs that are recycled as opposed to virgin material.

**Recycling facility** -- A facility which recycles lithium-ion batteries and is therefore considered a hazardous waste processor.

**Recycling rate** -- The percentage of batteries reaching their EOL that are recycled.

**Refurbishing** -- “Modification of an object that is waste or a product to increase or restore its performance and/or functionality or to meet applicable technical standards or regulatory requirements, with the result of making a fully functional product to be used for a purpose that is at least the one that was originally intended”<sup>102</sup>

**Remanufacturing** -- “A standardized industrial process that takes place within industrial or factory settings, in which cores are restored to original as-new condition and performance or better. The remanufacturing process is in line with specific technical specifications, including engineering, quality, and testing standards, and typically yields fully warranted products. Firms that provide remanufacturing services to restore used goods to original working condition are considered producers of remanufactured goods.”<sup>102</sup>

**Repurposing** -- Configuring used batteries into systems to be utilized in a different application, most commonly stationary storage. Also referred to as 2nd life or battery second use.

**Reuse** -- Batteries from a retired vehicle are reused in another vehicle.

**Second-life** – Use of a degraded electric vehicle battery in a stationary, secondary application, usually referring to a system where the battery pack has been removed from the vehicle after some years of service in a traction application.

**Sorting facility** -- A facility which tests and sorts LIBs based on their capability to be reused, repurposed, or remanufactured and then directs the batteries to be before being sent to either repurposing, reusing, remanufacturing or recycling.

**Transition metal** -- A classification of elements indicative of metals that are harder and less reactive than alkaline earth metals.

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## 12. APPENDIX: ADVISORY GROUP VOTING OUTCOMES AND SURVEY RESULTS

**Table A1:** Voting outcomes for Dec 7, 2021 and levels of support for supporting policy proposals

Policy Proposal	In Favor	Opposed	Abstain	Percent in Favor
Identify strategies to reduce the burden of transportation	15	0	0	100%
Universal waste interpretation	15	0	0	100%
Physical Labeling Requirement	14	0	1	93%
Develop training materials	14	0	1	93%
Develop strategic collection and sorting infrastructure	14	0	1	93%
Electronic Information Exchange	13	0	2	87%
Support enforcement of unlicensed dismantling laws	13	1	1	87%
Economic incentive package provided to lithium-ion battery recyclers within California	11	1	3	73%
Expand eligibility for relevant incentive programs to include reused and repurposed batteries	10	1	4	67%
Establish a timeline for hazardous waste processing permit	9	0	6	60%
Require pre-approval to bid on EVs at auctions	9	2	4	60%
Universal Diagnostic System	8	4	3	53%
Minimum material recovery rates	7	6	2	47%
Recycled content standards	7	7	1	47%
Third-party Verification	6	7	2	40%
Design for reuse, repurposing and recycling	5	6	4	33%
Develop a reporting system for EV batteries retired from use	5	6	4	33%
Develop a reporting system for lithium-ion battery recycling recovery rates	5	5	5	33%
Economic incentive package to encourage disassembly within California	3	3	9	20%

**Table A2:** Full voting record of Advisory Group members. F = In Favor, O = Opposed, A = Abstain, R = Recused, X = Absent. Legend for column titles: SA Recycling LLC: SA; Alliance for Automotive Innovation: AAI; Umicore USA: UMI; KBI: KBI; Honda Trading America: HO; CalEPA: CEPA; Ford Motor Company: FM; The Rechargeable Battery Association: PRB; CA & NV IBEW-NECA Labor Management Cooperation Committee: IBEW; Earthworks: EW; Californians Against Waste: CAW; Southern California Association of Governments: SCA; Tesla inc: TES; HHW at large: HHW; Surplus Service: SS; California Energy Commission: CEC; CalRecycle: CR; California New Car Dealers Association: CND; Department of Toxic Substances Control: DTSC

Organization	SA	AAI	UMI	KBI	HO	CEPA	FM	PRB	IBEW	EW	CAW	SCA	TES	HHW	SS	CEC	CR	CND	DTSC
Core exchange and vehicle backstop	F	F	F	F	F	R	F	F	F	F	F	F	A	F	F	R	R	F	R
Producer take-back with no companion legislation	F	O	F	F	O	R	O	F	F	F	F	F	F	F	O	R	R	A	R
Producer take-back with companion legislation	O	O	O	O	O	R	F	O	O	F	O	F	A	F	O	R	R	O	R
Environmental handling fee applied at the time of	O	O	A	O	O	R	O	O	F	F	F	F	O	F	F	R	R	A	R

Organization	SA	AAI	UMI	KBI	HO	CEPA	FM	PRB	IBEW	EW	CAW	SCA	TES	HHW	SS	CEC	CR	CND	DTSC
purchase																			
Environmental handling fee gathered through vehicle registration fee	O	O	A	O	O	R	O	O	A	F	F	F	O	F	F	R	R	A	R
Environmental handling registration fee split between EV owner and manufacturer	O	O	O	O	O	R	O	O	F	F	F	F	O	F	O	R	R	A	R
Physical Labeling Requirement	F	F	F	F	F	R	F	F	F	F	F	A	F	F	F	R	R	F	R
Electronic Information Exchange	F	F	F	F	F	R	F	F	F	F	F	A	F	F	F	R	R	A	R

Organization	SA	AAI	UMI	KBI	HO	CEPA	FM	PRB	IBEW	EW	CAW	SCA	TES	HHW	SS	CEC	CR	CND	DTSC
Universal Diagnostic System	F	O	A	F	O	R	O	O	F	F	F	F	A	F	F	R	R	A	R
Economic incentive package provided to LIB recyclers within California	O	F	F	F	F	R	A	F	F	F	A	A	F	F	F	R	R	F	R
Economic incentive package to encourage disassembly within California	O	A	A	O	A	R	A	O	F	F	A	A	A	A	F	R	R	A	R
Establish a timeline for hazardous waste processing permit	F	A	A	F	F	R	A	F	F	A	A	A	F	F	F	R	R	F	R



Organization	SA	AAI	UMI	KBI	HO	CEPA	FM	PRB	IBEW	EW	CAW	SCA	TES	HHW	SS	CEC	CR	CND	DTSC
Expand eligibility for relevant incentive programs	F	A	F	F	A	R	A	F	F	F	F	F	O	F	F	R	R	A	R
Minimum material recovery rates	O	O	F	O	O	R	F	A	F	F	F	F	O	F	O	R	R	A	R
Design for reuse, repurposing and recycling	O	O	A	A	O	R	O	O	F	F	F	A	O	F	F	R	R	A	R
Third-party Verification	O	A	F	O	O	R	O	O	F	F	F	F	O	F	O	R	R	A	R
Support enforcement of unlicensed dismantling laws	F	F	F	F	F	R	F	F	F	F	A	F	F	F	O	R	R	F	R
Develop training materials	F	F	F	F	F	R	F	F	F	F	F	A	F	F	F	R	R	F	R

Organization	SA	AAI	UMI	KBI	HO	CEPA	FM	PRB	IBEW	EW	CAW	SCA	TES	HHW	SS	CEC	CR	CND	DTSC
Identify strategies to reduce the burden of transportation	F	F	F	F	F	R	F	F	F	F	F	F	F	F	F	R	R	F	R
Develop strategic collection and sorting infrastructure	F	F	F	F	F	R	F	F	F	F	F	F	F	F	A	R	R	F	R
Universal waste interpretation	F	F	F	F	F	R	F	F	F	F	F	F	F	F	F	R	R	F	R
Recycled content standards	O	O	F	F	O	R	O	O	F	F	F	F	O	F	O	R	R	A	R
Develop a reporting system for EV batteries retired from use	A	O	A	O	O	R	F	O	A	F	F	F	O	F	O	R	R	A	R

Organization	SA	AAI	UMI	KBI	HO	CEPA	FM	PRB	IBEW	EW	CAW	SCA	TES	HHW	SS	CEC	CR	CND	DTSC
Develop a reporting system for lithium-ion battery recycling recovery rates	O	A	A	O	O	R	O	A	F	F	F	A	O	F	F	R	R	A	R
Require pre-approval to bid on EVs at auctions	F	F	F	F	F	R	F	F	A	F	A	A	O	A	O	R	R	F	R

**Table A3: Survey results<sup>4</sup>**

<b>Policy</b>	<b>Strongly Oppose</b>	<b>Oppose</b>	<b>No opinion</b>	<b>Support with modifications</b>	<b>Support</b>	<b>Strongly support</b>
Producer take-back (returning the battery to the auto manufacturer at end-of-life is required)	3	4	5	2	3	3
Producer take-back (returning the battery to the auto manufacturer at EOL is optional)	1	4	7	1	4	2
Core exchange and unwanted vehicle backstop proposal	1	1	7	2	7	2
Environmental handling fee used to finance an EOL management program	6	1	7	1	2	3
Added electric vehicle registration fee to finance an EOL management program	3	3	7	1	2	4
A yearly fee split between the auto manufacturer and the EV owner at vehicle registration	4	3	5	0	3	5
Define the current owner as the responsible party for EOL management	6	8	1	1	2	2
Physical labeling requirement	0	0	1	1	5	13
Electronic information exchange (i.e. QR code with online database)	0	0	2	1	10	7
Universal diagnostic system	3	2	3	0	5	7
SOH data made accessible to third parties without specifying the mechanism	1	2	4	5	2	4
Establish a timeline for hazardous waste processing permit	1	1	6	4	4	4
Economic incentive package provided to lithium-ion battery recyclers	2	0	3	1	8	6

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<sup>4</sup> The survey results include those from Occupational Knowledge International, which was a member of the Advisory Group until Nov. 3, 2021.

<b>Policy</b>	<b>Strongly Oppose</b>	<b>Oppose</b>	<b>No opinion</b>	<b>Support with modifications</b>	<b>Support</b>	<b>Strongly support</b>
Expand eligibility for relevant incentive programs to include repurposed and reused batteries	1	2	5	4	2	6
Incentivize a disassembly industry within California	2	1	6	0	6	5
Minimum material recovery rates	5	2	2	0	4	7
Third-party verification	3	1	6	1	4	5
Develop a reporting system for lithium-ion batteries retired from use / exported batteries	2	7	1	1	6	3
Develop a reporting system for lithium-ion battery recycling recovery rates	2	6	3	3	5	1
Recycled content standards	4	4	2	5	2	3
Design for repurposing, reuse, and recycling	3	2	3	1	4	7
Develop training materials to address knowledge and capacity gaps	0	1	1	1	9	8
Support enforcement of unlicensed dismantling laws	0	1	1	0	4	14
Require pre-approval to bid on EVs at auctions	1	1	7	2	3	6
Interpretation of universal waste regulations	0	0	3	5	4	8
Develop strategic collection and sorting infrastructure	2	2	4	1	7	4
Identify strategies to reduce the burden of transportation	0	0	3	4	9	4