ESA Corporate Responsibility Initiative: Guidelines for End-of-Life and Recycling of Lithium Ion Battery Energy Storage Systems

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This guide is a product of the U.S. Energy Storage Association (ESA) Corporate Responsibility Initiative (CRI). ESA organized and coordinated the CRI, which launched in March 2019. By April 2019, thirty six (36) industry leaders signed a pledge "to engage in a good-faith effort to optimize performance, minimize risk and serve as an exemplary corporate citizen in the manufacturing, deployment, implementation, and operation of energy storage projects across the United States" and to contribute experts to a CRI Task Force to establish best practices in several areas, including end-of-life and recycling. As of publication, fifty-seven (57) companies and organizations are signatories to the pledge.

The purpose of these Guidelines is to (1) address the end-of-life (EOL) management challenges that arise as the stationary energy storage system (ESS) industry grows; and (2) serve as a reference for manufacturers, integrators, developers, financiers, asset owners and others to inform product development, project planning, execution and policy related to EOL management. The document is not a standard; it is intended to support those involved in energy storage projects to ensure that planning and protocols account for the eventual decommissioning of energy storage systems. ESA also published a white paper in April 2020 *End-of-Life Management of Lithium-ion Energy Storage Systems* that described the current status of Lithium ion (Li-ion) battery EOL management, including regulatory requirements, reuse and recycling technology options, and initiatives to address concerns around the approaching end-of-life of ESS. A forthcoming CRI product will provide a decommissioning plan template for Li-ion battery energy storage systems.

Disclaimer

These Guidelines are provided for information and awareness purposes only and offer an approach to developing an end-of-life management strategy for energy storage systems consistent with environmentally responsible stewardship. ESA assumes no responsibility or liability for the use of this document. Developers and facility owners are advised to consult with legal, accounting and insurance advisors concerning liability, accounting, and other issues associated with end-of-life management of energy storage systems.

It is important to note that this document is “living” and will require regular updates as recycling and reuse experience is gained and technology design evolves.

Acknowledgements

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Table of Contents

Acronyms & Abbreviations

CRI	Corporate Responsibility Initiative
DOT	U.S. Department of Transportation
EIA	Energy Information Administration
EOL	End-of-life
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESA	The U.S. Energy Storage Association
ESS	Energy Storage System
LFP	Lithium iron phosphate
NMC	Nickel manganese cobalt
NYSERDA	New York State Energy Research and Development Authority
OEM	Original Equipment Manufacturer
RCRA	Resource Conservation and Recovery Act
RD&D	Research, development & demonstration
SOH	State of health

1. Introduction and Summary

Technology advances, electrification of our economy and concerns about climate change are driving rapid decarbonization of the electricity and mobility industries. The electricity sector is integrating more and more renewable energy and the auto industry is moving towards electrical vehicles (EVs), with increasing demand to electrify medium- and heavy-duty fleet vehicles. To enable this transition and maintain reliability and resilience, deployments of stationary energy storage systems (ESS) are increasing rapidly. Industrial battery-based energy storage has become a well-established industry with exponential growth projected in the coming years.

The most prevalent energy storage technology in both EV and ESS applications – namely Lithium ion (Li-ion) batteries of various chemistries and types – are classified as hazardous waste upon reaching end-of-life (EOL). Managing advanced industrial batteries after their useful lives poses unique challenges for many stakeholders in the industry value chain. With deployments on a gigawatt-hour (GWh) scale of ESS battery systems planned, the industry must address an approach for managing the extensive fleet of advanced industrial batteries that are being deployed now and will need to be managed responsibly upon reaching end-of-life in future years.

Corporate responsibility encompasses environmental stewardship, particularly when a rapidly growing industry could generate EOL waste that poses environmental and safety risks. Such is the case with large-scale industrial Li-ion batteries. Given the currently limited opportunities for refurbishment and reuse for Li-ion ESS batteries, recycling represents the best practice for managing Li-ion ESS batteries at the end of their useful lives. Currently, only a handful of battery processors offer recycling in North America, but these options will likely expand as a response to the more immediate challenge of dealing with a surge of spent EV batteries reaching EOL earlier and in larger volumes than stationary batteries.

EOL management should be planned and executed from project inception through (and beyond) the project’s lifespan to minimize the environmental and financial impacts. All entities throughout the value chain have a role in supporting environmental stewardship, fiscal responsibility and responsible recovery and reuse of valuable materials that the industry needs for continued growth.

The EOL decommissioning of an energy storage system represents a future cost that the asset owner should recognize as a financial liability. Even though experience is limited for stationary storage systems, available estimates suggest that decommissioning costs can be significant even though they might occur 10 to 20 years from the installation date—depending on the specific battery chemistry and its operational duty cycle.

Current and future ESS owners should develop decommissioning plans that recognize this uncertainty in costs and update plans as new recycling opportunities and options emerge. Competition and stewardship objectives can spur innovation in contractual arrangements to share risk and cost, as well as encourage new firms with novel approaches to enter the market for decommissioning services.

Supporting the development of economically efficient, competitively neutral policies that promote recycling of both EV and stationary Li-ion batteries and help expand the battery recycling market is consistent with corporate responsibility and environmental stewardship. Growing a robust recycling market will expand the available opportunities for all Li-ion battery users, improve environmental outcomes and lower the cost of managing EOL batteries.

2. Li-ion ESS Decommissioning and Recycling

Battery-based ESS facilities have a finite lifespan, although owners have some discretion regarding the timing of decommissioning based on factors such as safety or performance degradation. The decommissioning process involves dismantling the ESS and removing it from the site in compliance with applicable federal and local rules governing the safe transport and disposition of used equipment and waste. The ESA white paper on EOL management described the basic processes and considerations along with an assessment of the technology and market status of current EOL options, including refurbishment for second life and recycling.[1]

We focus on recycling as currently the most relevant and responsible option because landfill disposal of large-format Li-ion batteries is neither safe nor legal, and because the prospects for refurbishing ESS batteries for second life applications are very limited at present.[2] Even though the Li-ion battery recycling industry is in its infancy with respect to capacity and scale, more efficient and sustainable recycling processes are under active development; therefore recycling ESS batteries currently qualifies as best practice for EOL management.

The EOL management of Li-ion battery ESS is inextricably linked to the burgeoning EV market and the experience with managing spent EV batteries around the world. So, while only a handful of battery processors currently offer recycling in North America, these options will likely expand as a response to the imminent surge of spent EV batteries. As stated in the ESA white paper:

> While ESS and EV Li-ion batteries have different applications, they share many material inputs and thus have similar reuse and recycle opportunities. Some of the practices that evolve to reuse and recycle EV batteries will influence, and sometimes determine, the end-of-life requirements and management practices applicable to stationary ESS batteries.[3]

The future availability and cost of battery recycling options for stationary storage will depend on how the recycling sector evolves to meet the near-term challenge of spent EV batteries. Because the ESS industry will likely benefit from EV industry innovations, the ESS industry has a vested interest in the recycling efforts of the EV industry.

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[1] See Energy Storage Association, *End-of-Life Management of Lithium-ion Energy Storage Systems*, April 2020.

[2] Refurbishing EV batteries for second life in stationary storage is more commercially promising than refurbishing ESS batteries, in part because battery state of health (SOH) generally is higher for discarded EV batteries than for ESS batteries no longer performing useful services.

[3] Energy Storage Association, *End-of-Life Management of Lithium-ion Energy Storage Systems*, April 22, 2020, p. 5.

Decommissioning Process

As with any other asset within the power sector, the decommissioning process for ESS involves dismantling and removing equipment and waste from the site in compliance with applicable federal and local rules governing its safe transport and disposition. An extensive array of Federal environmental and safety regulations governs the breakdown, packaging, transportation and disposition of spent Li-ion batteries from ESS facilities. The Federal rules are outlined in Appendix A, and the description of the decommissioning process below is derived from the ESA white paper.

The actual scope of decommissioning depends on project-specific conditions, type of system, and the disposition pathway chosen. In some cases, the battery modules are removed, while the balance of the system (controls, enclosures, etc.) remain and are re-used with new battery modules. In other cases, the full systems are replaced as integrated packages. If the site itself is being entirely decommissioned (no future energy storage or similar infrastructure will occupy it), contractual agreements govern the final state of the site (e.g. resulting in remediated land, residual foundations, gravel, etc.).

Once a used battery is removed from service and diverted toward end-of-life management, it is designated as “Universal Waste,” a special category of hazardous waste under EPA regulations. These rules generally require recordkeeping, labeling, and storage methods that keep material out of the environment, and they outline approved recycling or disposal pathways. The balance of plant can represent a significant quantity of materials, including concrete pads, steel enclosures, cabling, and an array of electronics that are part of the entire energy storage system package. Concrete and steel are readily recyclable, and many enclosures can be reused—particularly if a site is being repowered with new batteries at the end of old equipment’s lifespan. Inverters, control systems, and other electronic equipment share many of the challenges of e-waste more broadly, but useful materials often can be recovered.

After dismantling and removal from the site, the old batteries are transported to facilities for refurbishment, recycling, or disposal. Transport of batteries, whether new or used, is governed by U.S. Department of Transportation (DOT) regulations that treat batteries as “Class 9” miscellaneous hazardous material and specify packaging and materials containment to mitigate the risk of accidental activation or reaction of the batteries during transport.

When batteries arrive at a processing plant for recycling, regulations apply for proper waste storage and handling. The recycling process begins with dismantling electrically discharged batteries. The current diversity of Li-ion battery types, sizes, and chemistries makes this process difficult to automate, so it is largely done manually. The steps consist of removing the battery casings, separating the connectors, disassembling modules from packs, separating cells from modules, and removing the electrolyte. In addition to manual separation, some recyclers employ ultrasound and/or mechanical agitation to remove cathode material. After shredding, or milling and pre-treatment, the cells undergo one of two types of currently available recycling processes: pyrometallurgical and hydrometallurgical. These processes recover different amounts and types of material from the batteries, which are sold in commodity markets, and the remaining non-hazardous materials are disposed in landfills qualified to accept the waste stream. It should be noted that while reintroduction of recovered materials back into markets can yield environmental benefits from the reduced use of virgin materials, this must be compared to the energy use and emissions from the recycling processes themselves, which can offset those benefits.

The steps in the recycling process – dismantling, packaging, transporting and processing – are governed by multiple, overlapping environmental and safety regulations that require specialized expertise and involve considerable labor at either the ESS site, the recycling facility, or both. Accordingly, the costs of decommissioning Li-ion ESS can be substantial today.

Current Estimates of Decommissioning and Recycling Cost

Not many ESS facilities have been decommissioned, so detailed cost figures based on actual experience are not readily available. There are several informal estimates, and the Electric Power Research Institute (EPRI) issued a study reporting formal, bottom-up ESS decommissioning cost estimates for several Li-ion chemistries in December 2017.[4] An update of that report is expected in the Fall of 2020.

Across the various assumptions, methodologies and base year dollars, the bulk of the estimates fall into the $25 – $75 per kWh range for the current costs of recycling the ESS battery modules. Cost variances are caused by (in rough order of importance):

- *Specific battery chemistries*, *e.g.*, Nickel Manganese Cobalt (NMC) or Lithium Iron Phosphate (LFP), which have different properties (e.g., density) that affect the costs of dismantlement and transportation; costs of different processes used; and the market value of specific recovered metals.
- *The recycling approach used*, which can range from milling or shredding modules with minimal disassembly and recovering 65-70 percent of the material, to dismantlement and segregation of material (e.g., plastics or metals) for different processes that can recover nearly 80 percent of the material. The latter approach can cost as much as 50 percent more than the direct milling approach, although the sales revenue from the enhanced material recovered under the second approach can offset some of the additional costs.
- *The amount of onsite vs. offsite labor* employed in disassembling the ESS, which can vary by system design. Some systems require extensive disassembly *in situ,* using more expensive non-local labor, while other systems can be transported nearly intact to processing facilities where permanent local-based labor rates are lower.
- *The distance between the ESS site and the processing facility*, which will impact transportation costs.

The balance of plant decommissioning costs could add roughly another $10/kWh to $15/kWh, although such costs are avoided entirely under a recommissioning scenario which involves swapping out old batteries and controls for new equipment but otherwise reusing the site for an ESS facility. Assuming a total ESS decommissioning and restoration of the site, most

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[4] See Renewance, Inc., “Commercial Liability Considerations for End-of-Life Industrial Batteries”; Carl Smith, “Market Trends and Considerations for End of Life and Recycling of Lithium Ion Batteries”; Energy Storage Association Webinar: End-of-Life and Recycling: Advanced Energy Storage Systems, January 29, 2020; and *Recycling and Disposal of Battery-Based Grid Energy Storage Systems: A Preliminary Investigation*, Electric Power Research Institute, December 2017.

decommissioning projects would cost between $35/kWh and $90/kWh. For a given battery type, chemistry and design, these unit costs—particularly those related to battery removal, disassembly, transportation and processing—should be roughly constant over a range of ESS sizes because of the nearly linear relationship between battery capacity and the volume and weight of battery cells/modules.

One way to put these costs into perspective is to compare the decommissioning cost estimates to the current capital cost of new ESS. Of course, ESS costs vary widely as well, but two recent estimates for large 4-hour systems provide fairly consistent benchmarks. BNEF calculates the capital cost of a 4-hour (20 MW/80MWh) system in 2019 at $331/kWh. Sargent & Lundy for the Energy Information Administration (EIA) estimates a 4-hour system (50MW/200 MWh) at $347/kWh, also in 2019 dollars.[5] Assuming a $350/kWh installation cost, and a range for decommissioning costs of between $35/kWh - $90/kWh, the installation of an ESS today implies a liability measured at about 10 to 26 percent of its current value, although such costs would be incurred perhaps 15-20 years in the future and thus require appropriate discounting to make valid economic or accounting comparisons.

It is also worth noting that the relationship between installation and decommissioning costs for batteries differ by chemistries; in some cases, the relationship is not proportional and may even be inverse. For example, NMC batteries with high cobalt content generally have a higher $/kWh initial installation cost than LFP batteries, but also typically have lower $/kWh net recycling costs because of the lower battery weight (higher energy density) and higher market value of recovered cathode material.

Decommissioning Cost Accounting

In accounting terms, future decommissioning cost responsibility represents a liability on the asset owner's balance sheet, sometimes called an "asset retirement obligation." Because an ESS inevitably is removed from service after reaching the end of its useful life, the future costs of proper disposal typically are recognized when the asset enters service.

Common accounting conventions used to calculate future liabilities assume that the underlying technology of decommissioning remains the same through time, which means that nominal costs would escalate at a general inflation rate. But since the decommissioning cost will be incurred years into the future, that escalated future cost then would be discounted back to the current year to determine the present value of the obligation. The discount rate typically used reflects the cost of borrowing for each corporation, and thus the discount rate is higher than the expected inflation rate.

As an illustration, consider an ESS that cost $350/kWh to build, $50/kWh to decommission (in today's dollars), and was expected to last 15 years. Assuming inflation at 2 percent per year, the cost of decommissioning this facility 15 years from today (escalated by 2 percent inflation)

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[5] See *2020 Sustainable Energy in America Factbook*, BloombergNEF in collaboration with the Business Council for Sustainable Energy, page 105 and *Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies* Energy Information Administration (EIA) February 2020, page 18-1 to 18-5.

would be $67/kWh. Assuming the owner applies a discount rate of 5 percent per year to future costs, the present value of the asset retirement obligation would be $32/kWh when the ESS was commissioned, or about 9 percent of the current cost of building the facility.[6] This would also represent the dollar amount the asset owner would set aside today to have just enough to cover the future cost of decommissioning, assuming the accumulated balance could earn 5 percent per year over 15 years.

Even appropriately discounted, decommissioning expense remains a material cost under the illustrative estimate presented above. The entire industry has a stake in reducing these costs while maintaining a high standard of environmental integrity. The composition of decommissioning costs suggests that cost savings are possible: much of these costs arise because most current batteries require significant manual labor to dismantle, package and transport safely, while other costs arise because of high fees paid to process batteries that are unprofitable to recycle with current recycling techniques and commodity prices. With sufficient incentive and focus, the ESS industry can work together toward reducing those costs.

3. Existing Facility EOL Planning Guidelines

The costs and risks inherent in decommissioning existing plants present additional challenges to owners and operators because the choices of location, technology, and contractual arrangements to manage costs have already been made. Under the Resource Conservation and Recovery Act (RCRA) regulations promulgated and enforced by the U.S. Environmental Protection Agency (EPA), the owner of the facility is the responsible party for properly managing waste upon retirement, because the owner’s decision to retire and decommission the facility “generates” the resultant waste. Owners may contract and offset their risk with engineering, procurement and construction (EPC) companies, battery manufacturers or other third parties for decommissioning services, including the management of waste material such as batteries destined for recycling, but ultimately the owner is liable for proper waste management.

The owner of an existing facility can manage the cost of decommissioning in some important ways:

- Revise decommissioning cost estimates to reflect new information, and when appropriate, update accounting entries;
- Develop a preliminary decommissioning plan (or update an existing plan); and
- Institute a process to explore and identify new options that might reduce the cost of decommissioning.

Information on decommissioning costs and expected remaining lifetime will certainly evolve, but the owner can and should develop current estimates for its facility and be ready to refine those estimates in light of new information on costs.

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[6] It is worth noting that ratios of estimated decommissioning cost to initial cost have increased significantly in the past few years due to the rapid decline in ESS capital costs along with relatively stable, or only slowly declining, estimated decommissioning costs.

Decommissioning plans can also evolve over time to become more specific and actionable by taking advantage of emerging opportunities in the market. For example, a new battery processing facility capable of handling a specific ESS battery might open at a location closer than originally thought, reducing estimated transportation and processing costs. New companies might enter the market to consult or manage the decommissioning process. As the end of a facility life nears, more of the decommissioning plan can be finalized, including executing contracts to perform the needed decommissioning tasks. Thus, new options that arise in the market for decommissioning services can lead to both downward revision of estimated costs as well as opportunities to manage costs prior to expected retirement of the facility.

4. EOL Considerations for ESS Under Development

The opportunities to minimize the eventual costs of decommissioning an ESS while the facility is under development are much broader - both at the facility level as well as industry-wide. Some of these opportunities arise because the project development and installation process involves multiple parties that could share the risks and costs of eventual decommissioning. These parties might include (in roughly supply chain order):

- *Original Equipment Manufacturers (OEM)* who produce the battery cells and modules for installation in ESS
- *Integrators* who combine batteries with other electrical and control systems
- *Developers* who arrange for financing and orchestrate the overall project completion
- *Engineering, procurement & construction (EPC) contractors* who build the facility
- *Operations & maintenance (O&M) providers* who keeps the ESS operating
- *Off-takers or utilities* who own or purchase services provided by the ESS

More than one of the functions described above may be performed by a single party; for example, a developer may own and operate ESS facilities and build systems for other owners. Some developers also serve as EPC contractors, and EPC contractors often provide ongoing O&M services.

Considerations affecting EOL decommissioning costs and environmental impacts reside throughout the supply chain. While the transactions from the manufacturer of individual battery cells through the commissioning and operation of an ESS system will largely determine the cost and environmental profile of EOL decommissioning, downstream entities such as developers can influence upstream decisions with their planning, procurement and project development process. Insofar as developers and owners especially can be responsible for multiple functions across the supply chain, they are in an advantageous position to optimize the upstream and downstream considerations for EOL.

Design for Recycling

Developers and project owners alike should assess the cost and environmental implications of ESS decommissioning projects early in the planning and procurement phase. Since dismantlement of ESS facilities is a significant cost component, designs that reduce disassembly time and cost could emerge as a competitive advantage for OEM battery manufacturers. For example, some recycling processes require the separation of individual battery cells from modules/packs, which can be labor intensive and costly. Reducing the labor required to "reverse manufacture" batteries will lower dismantlement costs. In addition to evaluating a battery manufacturer's product for initial cost and in-service performance, developers can also scrutinize how readily the modules can be disassembled upon retirement as may be necessary for processing or recycling. Likewise, packaging for legal transport of battery waste can be labor intensive, while battery cells and modules could have standard designs that would allow reusable containers and thus further reduce costs.

The recycling cost of different Li-ion battery chemistries can easily vary by a factor of two or more, which will have a significant impact on overall decommissioning costs.[7] Battery designs with longer expected service life directly increase the returns from the project, but also enhance asset value by deferring decommissioning costs and reducing the environmental impact of the broader ESS manufacturing industry. Integrators and EPC contractors can design large ESS projects to allow equipment access for easier field dismantlement or even moving entire containers offsite. When system integrators, EPC contractors and developers work together to incorporate the likely costs of decommissioning into financial evaluations, the EOL costs will become a competitive factor in selecting firms to supply the project.[8]

Cost is not the only metric to consider, however. A company's environmental stewardship objectives, community relations, and reputation will factor into these decisions. A commitment to recycling or other sustainable disposition of spent batteries will sometimes cost more than would minimal compliance with applicable disposal rules and regulations. However, responsible ESS owners should be willing to pay a modest premium for environmentally preferable options such as recycling—especially considering the rapid decline in installed costs of the past five years and projected out across the decade.

Another example of downstream entities influencing supply chain decisions and outcomes is the emerging occurrence in which buyers of ESS services (e.g. utilities and other off-takers) require a demonstrated commitment to EOL recycling/reuse as a qualification in their Requests for Proposals and other procurements. Some purchasers are beginning to require transparency of developers' energy storage decommissioning plans in bids and state-funded programs. For example, Portland General Electric is now requiring explicit decommissioning responsibilities in its requests for proposals. The New York State Energy Research and Development Authority (NYSERDA) Energy Storage Guidebook specifies that applicants for new energy storage projects have a decommissioning plan and a decommissioning fund.[9] NYSERDA requires a

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[7] For example, EPRI calculated a recycling cost of $18/kWh for Nickel Manganese Cobalt Oxide (NMC) batteries from one manufacturer and $82.50/kWh for Lithium Iron Phosphate (LFP) from another manufacturer. See *Recycling and Disposal of Battery-Based Grid Energy Storage Systems: A Preliminary Investigation*, Electric Power Research Institute, December 2017, Table 3-3, page 3-4.

[8] These evaluations may involve tradeoffs between initial capital cost and EOL cost. For example, an NMC battery with high cobalt content would have a higher initial cost than an alternative chemistry such as LFP, but the LFP battery may cost more to recycle due to less value in the recovered material. While the initial cost reduction would outweigh the present value of EOL cost increase in most cases, these tradeoffs should be explicitly analyzed.

[9] NYSERDA. *New York Battery Energy Storage System Guidebook for Local Governments*. March 2019.

narrative description of the decommissioning process, the estimated life of the energy storage system, details about the estimated cost of decommissioning and plans for ensuring its funding, and contingency plans for removal of damaged batteries.

Allocating Contractual Responsibility for End-of-Life

As discussed before, the ESS owner is the legally liable party for complying with hazardous waste rules for battery disposal upon the end-of-life. Most ESS project development and operation contracts to date have remained silent on the responsibility of managing end-of-life and decommissioning, and thus by default align cost responsibility with legal liability. However, responsibility and cost can be assigned to other parties during the project development phase. It is becoming more common for contract language to specify where ESS decommissioning responsibilities lie, for example, with the O&M provider or EPC contractor.

Other arrangements are possible among parties involved in ESS development as well as outside third-party decommissioning service providers. In cases where the project developer and the system integrator jointly design, implement and deploy the system, the contract between the developer and the system integrator could address EOL management. This could take many forms; for example, the developer could assume the obligations (and even retain the obligation in the event of a subsequent sale of the ESS) or the developer could opt to contract with the system integrator for EOL management. The specific terms and division of responsibility must be negotiated and agreed, and EOL management could be included under the existing capex or O&M contracts, or a separate contract altogether.

The intent and effect of such arrangements would be to allocate EOL cost and performance risks to parties who may be in a better position to manage that risk, and by separating the obligation from the owner, enhance the value of the asset. This reallocation of risk and responsibility can be efficient, for example, when other parties in the supply chain can accumulate more ESS decommissioning experience than owners who may only have one or several such installations and thus lack the requisite expertise. In these cases, OEM battery manufacturers, system integrators, specialized EPC firms or ESS developers may have significant cost advantages in managing EOL. For instance, an OEM battery manufacturer could agree to take back batteries for recycling at the end-of-life, an arrangement that could be reflected in the initial battery cost or be paid under an O&M contract. Many arrangements are possible, whereby an ESS owner who compensates a counterparty to manage EOL would save money at the end-of-life, while the counterparty assuming those obligations would be compensated for the cost and risk.

Defining and explicitly allocating responsibility up-front during a project's development phase can manage an important ownership risk factor, and such contracts would also reflect a company's position on environmental stewardship, financial risk and reputation.[10] In the present state of the industry, current industrial battery recycling costs are driven by limited process technologies, the amount of material recovered and the relevant commodity prices, all of which are highly speculative over the next 10 to 15 years and would make a fixed price guarantee on

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[10] Such contracts can convey with ESS ownership changes, with new owners assuming the terms and conditions.

EOL management for recycling difficult to secure today. But it is entirely possible for parties to design contracts reflecting potential changes under flexible pricing formulas.

When obligations and risks are allocated to the parties who are best able to efficiently manage them, the overall project risk declines. As such arrangements become the norm, EOL risks will become more transparent and certain, further increasing the bankability of ESS projects. For example, an ESS project with a relatively certain present value decommissioning cost of about 10 percent of the initial value would be more financially attractive than one with uncertain liability ranging anywhere from 5 to 15 percent of the initial cost. If a contract that features decommissioning price certainty also includes enforceable terms to recycle batteries, then a growing number of financiers who are building environmentally sustainable portfolios would find the transaction more attractive as well.

5. Industry Action to Promote and Improve Recycling

It is in the best interest of the energy storage industry to join those individual companies that commit to sustainable practices, in support of programs and policies that will enable the market for battery recycling to grow. Supporting the development of economically efficient, competitively neutral policies that promote reuse and recycling of EV and ESS Li-ion batteries is consistent with corporate responsibility, environmental stewardship and profitable long-term business practices. While this may impose some short-run costs on the industry, it will set best practices to encourage all players to manage EOL matters in a sustainable way and on a level playing field. Over the long run, stronger recycling policy will encourage new design, installation, operating and decommissioning practices in the ESS industry and stimulate the development of innovative recycling approaches, technologies and companies to meet market needs. This would expand the available opportunities for all Li-ion battery users, improve the environmental outcomes, and ultimately lower the cost of managing end-of-life batteries.

An evolving federal, state and local regulatory framework governs the end-of-life disposition of large industrial Li-ion batteries. In addition to regulatory compliance, some companies and industries have embraced paradigms such as product stewardship and extended producer responsibility, which encourage entities throughout the supply chain to assume responsibility for sustainable practices for products at the end-of-life. These concepts frequently underlie industry-wide approaches and initiatives to promote sustainable waste management and are explained in the Appendix B.

The Li-ion battery recycling market currently is focused on the rapidly growing number of EV batteries reaching end-of-life now and in the immediate future. It is in the best interest of the ESS industry to support EV battery recycling since it will expand the opportunities for ESS Li-ion battery recycling and reduce costs over time. Likewise, the ESS industry might benefit by supporting second-use refurbishment of EV batteries for some stationary service applications. Such batteries could serve niche markets such as remote location backup power.

It is also in the best interest of the ESS industry to support and encourage investment in research, development, and demonstration (RD&D) for improved battery recycling methods. Innovation that reduces EOL cost and improves environmental outcomes—for example, recycling processes that do not require battery disassembly and use less energy—would help reduce the environmental footprint of the Li-ion battery industry and help spur the development of a North American “reverse supply chain” to close the loop between battery EOL and manufacturing.

6. Conclusion

The cost and environmental implications of ESS end of life decommissioning are considerable, and largely beyond the influence of any single company that owns and operates an ESS facility. However, especially considering the growth of the EV battery recycling market, these costs and environmental outcomes will evolve, and these changes will arise from individual companies adopting best practices, industry-wide initiatives to support sustainable market expansion, and changes to policies and regulations at the federal, state and local levels. Improvements in costs and environmental outcomes can arise from:

- Programs and policies to encourage recycling of Li-ion batteries
- RD&D funding directed at new recycling technology
- Increasing knowledge of EOL costs
- Early consideration of EOL costs in ESS project development
- Market-driven competition focused on environmentally sustainable EOL cost reductions

The U.S. Energy Storage Association continues to lead the U.S. storage industry and engage with key stakeholders to foster innovation and advanced practice guidelines in emergency preparedness, safety, supply chain, end-of-life and recycling issues. To learn more about how ESA is working proactively on these issues, and to join our efforts, visit ESA Corporate Responsibility Initiative to obtain previously-published resources and information on forthcoming products.

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Appendix A: Federal Regulation of Li-ion Waste Batteries

A number of regulatory requirements affect the transportation, handling, storage and disposal of batteries throughout their lifecycle. At the beginning of life, and throughout the lifecycle, most batteries used in energy storage applications are considered hazardous material and regulated by the US Department of Transportation Hazardous Material Regulation (HMR) under Title 49 of the Code of Federal Regulations, Subchapter C. While many are aware that the HMR regulates the packaging, marking, labeling and transporting of hazardous materials, it also contains requirements for training, safety, security and recordkeeping that apply to anyone who handles hazardous material.

When a battery reaches the end of its useful life and is destined for disposal, it is considered waste and additional regulations apply. The US Resource Conservation and Recovery Act (RCRA) regulates the generation, transportation, treatment, storage and disposal of hazardous solid wastes under Title 40 of the Code of Federal Regulations, parts 262 through 273. Because of the regulatory burden associated with managing hazardous wastes, the US EPA created Universal Waste regulations to ease the burden and promote the collection and recycling of commonly generated wastes, including batteries. Intact batteries that classify as hazardous waste may be managed as Universal Waste, while batteries that are not intact, such as a battery that has been damaged to the point of leaking electrolyte, must be managed as a fully regulated hazardous waste.

The Federal RCRA guidelines represent the minimum requirements for state regulation but states may invoke more stringent requirements at their discretion. In California, federal RCRA requirements have been implemented through the California Code of Regulations (CCR), Title 22, Division 4.5. To a large degree, they follow the Federal regulations, except that California has further prohibited landfilling of batteries. New York has implemented Federal regulations in Title 6 to the New York Code of Rules and Regulations, which also closely follows Federal regulations for management of Universal Waste.

Under RCRA, the waste generator is obligated to determine whether its waste is a hazardous waste and regulated under RCRA. The waste generator is defined by RCRA as “any person, by site, whose act or process produces hazardous waste identified.” This would typically be the owner/operator of the battery energy storage system as the operation and use of the battery led to the need for disposal. A hazardous waste may be specifically listed by the EPA or exhibit characteristics of ignitability, corrosivity, reactivity, or toxicity under prescribed testing conditions. Lithium ion batteries, one of the most common technologies used in battery energy storage applications, are not listed specifically as a hazardous waste, but many possess characteristics that trigger RCRA regulations.

Beyond waste classification, RCRA imposes several additional requirements with respect handling, storage, transportation and disposal. The requirements vary depending on the volume of waste that is being generated, so it is important for waste generators to understand the volume thresholds and associated obligations. These obligations may include:

- Understanding the **on-site accumulation limits** which define the amount of hazardous waste/universal waste a generator is allowed to "accumulate" on site without a permit.

- Obtaining an **EPA Identification Number**, which is a unique number that identifies the generator by site. The EPA ID number must be obtained prior to exceeding the on-site accumulation limits.
- Monitoring and complying with **accumulation time limits** which define the amount of time hazardous/universal waste is allowed to accumulate on site.
- Ensuring appropriate personnel complete classroom or on-the-job **training** to become familiar with proper hazardous/universal waste management and emergency procedures for the wastes handled at the facility.
- **Maintaining records** demonstrating compliance with the regulations, including tracking off-site waste shipments. Records must be retained for a defined period of time (typically 3-years).

Liability

Hazardous material and hazardous waste regulations govern the management of batteries through their lifecycle. Understanding those obligations is important since failure to comply has consequences, and some of those consequences including reputational damage, financial penalties and even imprisonment for the most severe violations.

Violations of the HMR can carry both civil and criminal penalties. A civil penalty involves fines of up to $79,976 for each violation, or up to $186,610 if the violation results in death, serious illness, or severe injury to any person or substantial destruction of property. A person who knowingly, willfully or recklessly violates a requirement of the HMR can be imprisoned up to 5 years. If the violation involves the release of a hazardous material which results in death or bodily injury to any person, the maximum penalty increases to up to 10 years in prison.

Failure to comply with RCRA regulations can also result in civil or criminal penalties. Civil penalties for those who violate the regulations carry a fine of up to $74,553 per day, per violation. A person who knowingly violates RCRA hazardous waste regulations is subject to a penalty of up to 5 years in prison. Penalties double for subsequent violations. If a person committed such a violation while knowing that such an act put another person in imminent danger of death or serious bodily injury, the penalty increases to 15 years and/or up to $250,000 for an individual or $1,000,000 for an organization.

While not all violations will carry the maximum penalties, enforcement actions are openly communicated by the responsible US agencies and the resulting damage to a company's reputation resulting from a violation can be significant but difficult to quantify in monetary terms.

Transport

Lithium batteries are regulated as a hazardous material under the U.S. Department of Transportation's (DOT's) Hazardous Materials Regulations (HMR; 49 C.F.R., Parts 171-180). The HMR apply to any material DOT determines could pose an unreasonable risk to health, safety, and property when transported in commerce. Lithium batteries must conform to all applicable HMR requirements when offered for transportation or transported by air, highway, rail, or water.

A number of regulations apply to the transport of end-of-life lithium batteries depending on the rated energy capacity, weight, construction, quantity, condition and intended use. Batteries used in ESS systems will need to consider the following:

Classification

If a battery is being shipped for reuse, must be subject to a series of design tests per sub-section 38.3 of the UN Manual of Tests and Criteria. Downstream shippers and consumers, however, often cannot confirm if their battery was successfully tested. To address this issue, some lithium battery and device manufacturers provide product information sheets with this information, however, this is not a wide-spread practice. The UN Model Regulations now have a requirement for lithium battery manufacturers and distributors to make available lithium battery test summaries (TS) using a standardized set of elements. Lithium Ion batteries shipped for recycling are excepted from this requirement.

Design/Construction

Lithium cell or battery must incorporate a safety features that prevent violent rupture, short circuits and prevent dangerous reverse currently flow. Batteries that have a strong, impact-resistant outer casing may be excepted from UN performance packaging requirements noted below. Batteries or battery assemblies must be secured to prevent inadvertent movement, and the terminals may not support the weight of other superimposed elements. Batteries or battery assemblies packaged in accordance with this paragraph are not permitted for transportation by passenger-carrying aircraft, and may be transported by cargo aircraft only if approved by the Associate Administrator.

Packaging

A fundamental requirement of any shipment is that lithium ion batteries must be packaged in a manner to prevent, short circuits, movement within the outer package; and accidental activation of the equipment. Unless otherwise excepted batteries must be placed in an inner packaging (such as a plastic bag), that surrounds the battery and prevents contact with other devices or conductive materials. The batteries must them be packed in an outer packaging, constructed of selected materials, that meet specific UN performance packaging requirements. A number of off-the-shelf packaging solutions exist that meet UN performance packaging requirements, though it can be difficult to find an optimal solution depending on the form factor of the battery to be shipped. In those cases, custom packages can be constructed and certified to UN specification requirements.

Containerized shipments

Shipment of containerized systems is growing in popularity as it offers the potential of system level acceptance testing prior to shipment and streamline installation of the system at site. The UN Model Regulations has adopted shipment of containerized systems, officially referred to as Cargo Transport Units, and has assigned UN 3536. However, the US DOT has not adopted the new regulations for shipment of Cargo Transport Units. US DOT will allow the transport of UN 3536 shipments within the US if it the continuation of an international shipment under an IMDG bill of lading. Domestic shipments wholly within the US is only allowed with prior approval by the US DOT.

Damaged, Defective or Recalled Lithium Ion Batteries

Lithium cells or batteries, that have been damaged or identified by the manufacturer as being defective for safety reasons, that have the potential of producing a dangerous evolution of heat, fire, or short circuit (e.g. those being returned to the manufacturer for safety reasons) may be transported by highway, rail or vessel only, but must be packaged a certain way to meet safety regulations as specified at 49 CFR 173.185(f):

- Each cell and battery must be placed in individual, non-metallic inner packaging that completely enclose the cell/battery;
- The inner packaging must be surrounded by non-combustible, non-conductive, and absorbent cushioning material; and
- Each inner packaging must be individually placed in UN specification packaging meeting Packing Group I performance level (i.e., rated “X”).

The boxes or drums containing damaged lithium cells/batteries must be marked and labeled as any fully regulated lithium battery package. This includes:

- The Proper Shipping Name,
- The UN identification number,
- The shipper’s OR consignee’s name and address, and
- The Lithium Battery Class 9 label

In addition to the standard required markings and labels, the outer package must be marked with an indication that the package contains a “damaged/defective lithium ion/ metal battery or cell,” as appropriate.

Many off-the-shelf packaging solutions meeting the requirements above exist for shipping DDR consumer batteries. However, it can be far more challenging to find a solution for large format industrial. Some engineered solutions exist that permit reuse, but these can cost several hundred dollars, which is impractical for shipping larger quantities of DDR industrial batteries.

As mentioned, the US EPA permits large format lithium ion batteries to be managed as Universal Waste, providing for a streamlined set of regulations. However, batteries that show evidence of leakage, spillage, or damage that could cause leakage under reasonably foreseeable conditions must be placed in a container. The container must be closed, structurally sound, compatible with the contents of the battery, and must lack evidence of leakage, spillage, or damage that could cause leakage under reasonably foreseeable conditions. The person handling the batteries must determine whether the leaking materials exhibit a characteristic of hazardous waste and, if so, manage the damaged batteries as fully regulated hazardous waste.

Stranded Energy

Lithium ion batteries transported by ground (motor vehicle or rail) are not subject to a state of charge limitation. Lithium ion batteries shipped by aircraft or vessel must be discharged below 30% state of charge.

Training

The Hazardous Materials Regulations, 49 CFR 172.704, require each employer with employees who handle hazardous materials or hazardous waste must train and test those employees, certify their training, and develop and retain records of current training. Hazardous materials training must include general awareness/familiarization, function-specific, safety, security awareness, driver training (for each hazmat employee who will operate a motor vehicle). The training must be administered within 90 days of employment or change in job function. Recurrent training is required at least once every three years. Per 40 CFR 273.36, a large quantity handler of universal waste must ensure that all employees are thoroughly familiar with proper waste handling and emergency procedures, relative to their responsibilities during normal facility operations and emergencies.

Appendix B: Approaches to Achieve a Circular Economy

The U.S. Energy Storage Association recently released a white paper report that described the current status of Li-ion battery end-of-life management, including regulatory requirements, reuse and recycling technology options, the current economics of alternative EOL pathways and initiatives to address the challenges that arise in battery ESS EOL management.[11] The paper described reuse, recycling, and disposal options for ESS using the “circular economy” framework that underlies and motivates efforts to address EOL issues. In a circular economy, goods that reach the end of their useful lives are then reused and/or recycled as inputs again into the production process. The reintroduction of what was once considered disposable waste back into production can minimize material and energy used to provide economic goods and services, as well as reduce the volume of waste and environmental impacts from disposal. When implementation of circular economy principles results in reductions in overall energy and material use, they also contribute to greenhouse gas (GHG) reductions.

While the circular economy framework provides a sensible way to track potential material or energy flows and estimate the costs and benefits of various pathways and options, it does not imply any particular approach or policy design to realize reuse or recycling objectives. A circular economy requires the product slated for disposal to undergo both transportation (to an appropriate facility) and transformation (via a recycling or refurbishing process) before being reintroduced upstream in the supply chain. In some industries such as scrap metals, markets themselves support recycling because the value of scrap metal is high enough to provide payments for deliveries of waste and smelters and mills will pay for scrap as valuable feedstock for metal production.[12] However, most examples of reuse and/or recycling of final goods require some intervention in the market. The mechanisms employed to achieve these outcomes range from encouragements and incentives to prohibitions and mandates.

Many of the familiar programs at the consumer level have been promoted with “reduce, reuse, recycle” messages of individual responsibility. Voluntary collection of bottles, cans and paper are common, although such waste typically can be legally discarded in municipal waste streams. In other cases, prohibitions on disposal coupled with encouragement, incentives or requirements for locations to receive waste (such as gas stations that accept used motor oil for recycling from do-it-yourself oil changes, or hardware stores that accept spent batteries from portable power tools) help consumers “do the right thing” even when detection and strict enforcement of disposal prohibitions are nearly impossible. In some cases, mandatory policies are imposed and enforced. For example, 98% of vehicle lead-acid batteries are recycled under a disposal ban reinforced by a deposit refund program.

One approach to realizing circular economy objectives is known broadly as product stewardship. In the “linear economy” of production, consumption and waste disposal, the

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[11] Energy Storage Association, “End-of-Life Management of Lithium-ion Energy Storage Systems,” April 22, 2020.

[12] There are many examples where by-products from an industrial process that might otherwise be considered waste are used as inputs to other industrial production processes, but these transactions do not involve a finished good used by the ultimate consumer and then otherwise discarded, which is the focus of the circular economy.

responsibility for use and/or disposition follows each transaction through the supply chain. For example, natural gas producers will sell gas to chemical manufacturers, who chose to create plastic feedstocks, which manufacturers decide to mold into consumer products, which consumers purchase, use as they wish and dispose in municipal waste streams. Local governments provide waste removal and disposal services, which are supported by taxes and user fees, thus the financial obligations are socialized to local businesses and residents. At no point along this chain of transactions do the sellers retain any interest, obligation or liability to promote the reuse or recycling of the product, with the final consumer ultimately deciding on the end-of-life disposition (and ultimately paying for services through taxes or private haulers).

The concept of product stewardship is based on the premise that upstream manufacturers can play a positive role in environmental sustainability. The Product Stewardship Institute (PSI), which supports and designs policies that promote reuse and recycling, gives this definition:

> **Product stewardship** is the act of minimizing the health, safety, environmental, and social impacts of a product and its packaging throughout all lifecycle stages, while also maximizing economic benefits. The manufacturer, or producer, of the product has the greatest ability to minimize adverse impacts, but other stakeholders, such as suppliers, retailers, and consumers, also play a role. Stewardship can be either voluntary or required by law.

Some product stewardship advocates employ a moral framework to promote this concept, arguing that producers reap profits from sales, which creates an obligation to minimize adverse impacts from the product’s use and disposal. Other advocates simply note that producers may incur lower costs than consumers or governments when managing EOL (for example, when recycling their own products) and therefore represent an efficient pathway to attain circular economy outcomes. Regardless of the premise or motivation, product stewardship highlights the beneficial role that entities upstream in the supply chain can play in sustainability.

One strong version of product stewardship involves placing obligations on producers for post-consumer involvement with the product after its useful life, as well as increased consideration of more environmental impacts of design, including the ease and/or cost of reuse or recycling. This mandatory approach, called “extended producer responsibility” places some liability on EOL disposition on upstream suppliers, including in the design of products. The PSI definition states:

> **Extended producer responsibility** is a mandatory type of product stewardship that includes, at a minimum, the requirement that the manufacturer's responsibility for its product extends to post-consumer management of that product and its packaging. There are two related features of EPR policy: (1) shifting financial and management responsibility, with government oversight, upstream to the manufacturer and away from the public sector; and (2) providing incentives to manufacturers to incorporate environmental considerations into the design of their products and packaging.

These concepts define a range of options for various entities in the supply chain to act with sustainability in mind, either through voluntary commitments or responding to policy-driven incentives or mandates. Product stewardship provides a framework in which to consider industry approaches to sustainable management of energy storage systems as they reach the end-of-life.