ELECTRIC POWER RESEARCH INSTITUTE

Electric Sector Challenges in Circular Economies for Renewables and Batteries

Proceedings of the March 2021 Washington Seminar

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ABSTRACT

The race to low-carbon energy production is creating new opportunities and challenges for renewable energy and battery energy storage system materials to participate in circular economies. Projected end-of-life (EoL) material volumes by 2050 reach into the tens of millions of tons annually, leading to questions on how to produce safe and reliable low-carbon electricity that retains enhanced environmental stewardship characteristics, incorporates responsible EoL economics, and reduces regulatory and recycling/reuse market uncertainties. Developing sustainable and economic solutions will require research collaboratives between government entities, researchers, manufacturers, and recyclers.

These questions strongly intersect with the missions of multiple stakeholders, including EPRI, electric utilities, national laboratories and other research organizations, federal and state government agencies, academia, non-governmental organizations, plus the waste disposal and recycling industries. Cross-stakeholder collaborations are needed to identify the best pathways to convert renewable and battery storage EoL materials into assets that contribute to the circular economy and improve environmental responsibility, rather than creating a new waste stream that increases asset management cost and resource usage.

A March 2021 workshop, developed as part of EPRI's Renewables and Battery End-of-Life Strategic Initiative and held under EPRI's Washington Seminar Series, brought together stakeholders from several types of institutions and research areas to share ideas and knowledge about the opportunities and challenges that lie ahead. Presentation materials, an audio recording, and additional resources on the seminar and related content can be found at the event website.

https://www.epri.com/pages/sa/washington-seminar

Keywords
Circular Economy
Renewable Energy
Battery Energy Storage Systems
Recycling
Reuse

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1 INTRODUCTION

A circular economy is one in which usable materials re-enter manufacturing streams instead of being discarded. Some common principles that are managed in a circular economy are reduction of natural resource use and resource loss; life extension; recovery of embedded manufacturing value; designing for repair, reuse, or recycling; and consideration of social and equity opportunities. Circular economies can help enable the energy transition by facilitating additional deployment of low-carbon energy generation materials while reducing the social and environmental burdens typically incurred through use of high-carbon thermal energy generation. Working to move renewable energy and battery storage technologies into a circular economy is a path to enhancing the environmental gains implicit to these technologies.

The race to low-carbon energy production is creating new opportunities and challenges both to traditional energy generation and to the integration of renewable and battery storage materials into the circular economy. Globally, deployments of utility-scale renewables and battery storage have increased rapidly over the past 15 years and are projected to continue dominating new generation installations through 2050. The increase in solar photovoltaic (PV) and wind generation assets with 20-30-year lifetimes during this time period, and planned build out of 10-15-year lifetime battery energy storage systems (BESS) in the coming decade, suggests that increasingly large volumes of all three technologies may require end-of-life (EoL) management within the next 10 to 15 years. Projected end-of-life (EoL) material volumes by 2050 reach into the tens of millions of tons annually. This leads to questions on how to simultaneously retain the enhanced environmental stewardship characteristics of these technologies, incorporate responsible EoL economics, and reduce regulatory and recycling/reuse market uncertainties. In the U.S. and many other regions, there are currently no widely deployed reuse, recycling, or reclamation technologies, nor the associated infrastructure and programs, to bring these materials into the circular economy at EoL. Emerging options can be an order of magnitude more expensive than landfill disposal. Additionally, most products are not designed for ease of EoL management.

These questions strongly intersect with the missions of multiple stakeholders, including EPRI, electric utilities, national laboratories and other research organizations, federal and state government agencies, academia, non-governmental organizations, plus the waste disposal and recycling industries. Developing sustainable and economic solutions will require research collaboratives between all stakeholders. The goal is identification and facilitation of the best paths to convert renewable and battery storage EoL materials into assets, rather than creating new waste streams that increase asset cost and resource usage. Utilities and energy providers are in a unique position to improve circularity throughout the technology lifecycle by leveraging opportunities throughout production, purchasing, and asset management (Figure 1-1).

Figure 1-1
Electric Utility Roles in Renewable and Battery Circular Economies

EPRI's Washington Seminar Series brings stakeholders together around topics of relevance to both the electricity sector and the Washington policy community. Thought leaders from federal agencies, Capitol Hill, industry, academia, trade associations, NGOs, think tanks, and the electricity sector discuss emerging issues, research needs, and policy concerns on key topics. Past seminars have covered such diverse topics as the energy-water nexus, endangered species, electricity generation options, energy storage, the evolution of the electricity sector, and the implications of trees for climate resilience. A workshop on *Electric Sector Challenges in Circular Economies for Renewables and Batteries* was held under EPRI's Washington Seminar Series on March 23, 2021.

Workshop Objectives

Extended life, recycling, and reuse are the preferred options for end-of-life management of renewables and batteries from a sustainability perspective. Currently, research and development are underway to increase broad access to recycling, demonstrate successful reuse applications, improve the return on investment for initial costs, and improve infrastructure for transportation, storage, and separation. The regulatory/policy landscape has evolved rapidly in recent years, and many entities are investigating opportunities to develop a framework to support and encourage circularity.

The objectives of this workshop were to:

1. Identify the opportunities and challenges facing the power sector as companies manage disposition of end-of-life renewable and battery storage technologies;
2. Provide federal and state perspectives on current and developing regulatory and policy approaches that interact with circular economies for these materials; and
3. Offer research reviews of reuse and recycling advances relevant to utility-scale renewable and battery storage assets.

The workshop agenda for this Washington Seminar is provided in Table 1-1.

Table 1-1
EPRI Washington Seminar: Electric Sector Challenges in the Circular Economies for Renewables and Batteries Agenda

TUESDAY MARCH 23, 2021		
TIME	**TOPIC**	**PRESENTER**
1:00 p.m.	Welcome and Introductions	David Hunter, *Senior Advisor for Government and External Relations, EPRI*
1:05 p.m.	Opening Remarks	Neil Wilmshurst, *SVP, Energy Systems Resources, EPRI*
1:10 p.m.	Circular Economy for Renewables and Batteries: Challenges and Opportunities for Utilities and Power Companies	• Peter Perrault, *Senior Manager, Circular Economy & Sustainable Solutions, Enel North America* • Circe Starks, *Compliance Director, Southern Power* • Jeff West, *Senior Director, Environmental Services, Xcel Energy* Moderator: Neva Espinoza, *VP, Energy Supply and Low-Carbon Resources, EPRI*
1:50 p.m.	Federal and State Perspectives on End-of-Life Challenges for Renewables and Batteries	• Taylor Curtis, *Esq., Legal and Regulatory Analyst, NREL* • Matt Henigan, *Deputy Director, CalRecycle* • Hanjiro Ambrose, *Staff, California Air Resources Board* Moderator: David Hunter, *EPRI*
2:30 p.m.	*Break*	
2:40 p.m.	Technology Solutions and Research	• Chris Howell, *Senior Director, Recycling Operations, Veolia* • Tommy McGuire, *President, Echo Environmental* • Hugo Leduc, *Senior Electrochemistry Data Scientist, ReJoule* • Ben Lyon, *VP Business Development, RePurpose* Moderator: Ron Schoff, *Senior Program Manager – Renewable Generation, EPRI*
3:20 p.m.	Wrap Up and Next Steps	Stephanie Shaw, *Technical Executive, EPRI,* and Cara Libby, *Principal Technical Leader, EPRI*
3:30 p.m.	*Adjourn*	

Opening Remarks

In his opening remarks, Neil Wilmshurst, EPRI Senior Vice President of Energy Systems Resources, outlined some of the drivers for EoL research and development. He discussed the rapidly developing nature of renewable and battery energy technology composition and design and questioned whether we currently understand the full lifecycle impacts of the technologies, whether we can adequately predict EoL economics, and how we will address EoL management responsibly and sustainably. Mr. Wilmshurst framed these issues for power generators by asking: "*What are the choices for environmental and economically responsible end-of-life management if you're a producer of power? How are circular economy concepts incorporated as you procure these items? How do you manage assets?*"

He put an emphasis on recycling renewables and batteries once they reach the end of their first useful life. He compared it to the path of a mobile phone: when receiving a new phone, customers often trade their old phones for newer models. The old phone could be refurbished and put back on the market, scrapped for parts, or recycled.

There is a strong intersection between the mission of EPRI to support safe, reliable, affordable, and environmentally responsible electricity and the drivers for electric utilities and energy providers investigating EoL management opportunities, as those shown in Figure 1-2. Mr. Wilmshurst defined EPRI's role in the emerging circular economy for renewable energy resources and batteries as, "informing the choices that energy providers have when deploying renewables and battery energy storage." This role can include assisting utilities with understanding EoL options; estimating costs and providing case studies of decommissioning experiences; and participating in the fundamental research required to improve and demonstrate advances in technology manufacturing, recycling, and second life applications.

Figure 1-2
Electric Utility Drivers for End-of-Life Research & Development

2
SESSION OBJECTIVES AND KEY LEARNINGS

Session 1 – Circular Economy for Renewables and Batteries: Challenges and Opportunities for Utilities and Power Companies

The speakers who participated in this first panel represented two large energy companies and a regulated utility that are very active in deploying renewable generation assets and battery storage technologies. They offered unique perspectives on the opportunities and challenges to participating in the circular economy and discussed how they are taking action to (1) reduce their carbon footprint while balancing their generation portfolios, and (2) minimize risk and uncertainty while leveraging life extension, recycling, reuse, and circular economy opportunities.

EPRI's Neva Espinoza summed up the participants' views on a circular economy as, *"not just focusing on recycling, not just end-of-life. It's shifting to a more integrated life management approach."*

Panelists:

- Peter Perrault, *Senior Manager, Circular Economy & Sustainable Solutions, Enel North America*
  - Mr. Perrault presented Enel's goals for 100% decarbonization by 2050, and a phase-out of coal generation by 2027 along with an overview of the company's territory and assets. He highlighted three goals of the circular economy: designing out pollution, extending product life, and maintaining natural systems. Enel has adopted these principles with 5 pillars: sustainable or circular inputs, lifecycle extension, product as a service, sharing models, and new life cycles. Enel wants to begin the circular economy not at the end of life, but at the beginning during the product design phase, and look at the supply chain as a value chain that incorporates their 5 pillars throughout the entire system. This value chain applies not only at the point of manufacturers and suppliers, but their customers as well.
- Circe Starks, *Compliance Director, Southern Power*
  - Ms. Starks provided an overview of Southern Power's mission and objectives, highlighting their low-carbon and renewable assets. She presented Southern Power's business model that relies heavily on minimizing risk and uncertainty throughout the value chain. This is achieved in part by upfront verification of the source of materials and confirming that Southern Power's procurement process begins with the end in mind. They also evaluate each project from a whole-life perspective, ensuring that decommissioning and asset retirement obligations are captured and included in the project cost. Ms. Starks highlighted the need for appropriate sampling and testing methodologies to fully characterize materials in terms of their hazardous nature to facilitate compliance with federal and state regulatory requirements in the many states where operations occur. She also pointed out the importance of having federal regulations that allow efficiency gains throughout the operational lifecycle, as opposed to a

patchwork of local or state regulations that result in multiple management and transportation requirements that change depending upon the material location.

- Jeff West, *Senior Director, Environmental Services, Xcel Energy*
    - Mr. West introduced Xcel Energy's operations and assets, and highlighted that Xcel is a customer-owned regulated utility. He discussed the rapidity with which Xcel is retiring thermal generation assets and deploying renewable and low-carbon assets. Mr. West provided an overview of Xcel's carbon reduction goals: an 80% reduction from 2005 levels by 2030, and 100% carbon-free by 2050. He pointed out that the path to 100% decarbonization is not set, and that while the first 80% reduction is achievable, the final 20% reduction will require technology advances, policy implementation, continued use of nuclear assets, and positive regulatory treatment. Xcel plans to balance classic generation, flexible core generation, free fuel (wind and sun) new generation, nuclear, and hydro assets to continue providing affordable and reliable electricity during the decarbonization process. This commitment will be achieved in part by entering into the circular economy, where products are designed to eliminate waste and promote a continuous use of resources.

Key Learnings

The utilities and energy providers taking part in this discussion identified several key learnings and opportunities to improve the circularity of renewable and battery storage assets and facilitate participation by a wider range of asset owners. For each opportunity, the speakers agreed that the commitment to circularity begins at the executive level and flows out through the company in order to transform business practices to incorporate circularity in every step of the asset lifecycle, from planning and procurement, through operations, to EoL management. Panelists stressed that a circular economy begins with plant, product, and component design, and continues throughout the entire life cycle of a product. To make this possible, stakeholders must collaborate and address end-of-life opportunities upfront, whilst consistently working across the value chain to understand how changes at one link affect economic value or environmental aspects of other links. This approach eases cost uncertainty, maximizes reuse and recycling opportunities, encourages development and deployment of products with longer lifetimes, and promotes sound environmental choices. The waste hierarchy in Figure 2-1 illustrates the ideal product design to promote a circular economy.

Figure 2-1
Waste Hierarchy Guide for Designing Long-Life Products that Encourage Circularity and Minimize Waste

1. *Keep the end in mind from the beginning*

   The panelists agreed that the first step in creating a circular economy for renewables and battery technology is designing the products and facilities with this goal in mind. Enel looks for truly innovative business opportunities that improve the long-term cost of the technologies while capitalizing on opportunities such as material flows and commodity management.

   The best designs would be those that avoid waste creation by keeping the resource useful in its first life as long as possible, extending the first life, or directly use the resource in a "second life" application. The products could also be made more circular by designing for ease of repowering, repair, transportation, and disassembly. Utilities and other end users can facilitate this goal through the use of procurement specifications that require product designs with longer life expectancy and requirements for reuse, recycling, or reclamation at end of life.

   Enel is attempting to measure the inflows and outflows of materials throughout company operations globally to identify opportunities to recapture value from EoL materials. One example of how these metrics were subsequently used was designing their third generation of smart meters to be easily disassembled. Thus, the fourth generation of smart meters were manufactured from the third generation materials, rather than from new resources, reducing raw material extraction. Xcel Energy tracks equipment availability throughout its operating system to maximize equipment usefulness and longevity. Material usage is tracked throughout a project's lifecycle to identify what was used, recycled, or disposed. This information is used to subsequently work with vendors to identify improvements in material usage. Xcel Energy also tracks the carbon cost of material manufacture and transport to inform future decisions which can minimize the external costs of material usage.

2. *Change the conversation to focus on long-term value rather than short-term cost*

   Many conversations about asset EoL are focused on the cost of decommissioning. The focus on cost begins at project inception, and decommissioning costs are included as an asset retirement obligation when calculating the full project cost and value. Limited reuse, recycling, and reclamation options at this time, as well as uncertainty in future EoL costs, generally results in higher estimated costs as compared to disposal. Such costs may be challenged by ratepayers or regulators as unnecessary or wasteful spending.

   Participants suggested changing the conversation with ratepayers and regulators from the additional cost of circularity to the overall value of circularity. In this way, the opportunities presented by recycling and reuse, and the risks of not taking action, can be more clearly explained. As Peter Perrault pointed out, a study by Accenture identified up to $500 billion at risk to the electric industry by not embracing the circular economy[1]. In addition, he identified risks as including a negative company reputation, costs associated with managing changing and heterogeneous regulations, and the externalities in the extractive use of materials. Including the risks and external costs in the conversation shows the true value of the circular economy paradigm, which encompasses the potential for long-term natural resource and financial savings as well as reduced environmental and human health risks, and consequently may improve end user and regulatory acceptance of higher short-term costs.

3. *Identify and remove barriers throughout the value chain to enable the circular economy*

   Partnerships that involve collaborations throughout the value chain can enable information sharing and education to all stakeholders. It is important to understand how each step in the asset lifecycle, and related changes, affect economic value or environmental aspects of other steps. Greater communication among value chain entities will reduce uncertainty and facilitate development of win-win innovations through holistic assessments such as technoeconomic and environmental life cycle assessments. Such collaborations can also use the insights gained from asset owners and recycling or waste management companies to inform manufacturer efforts on product design in a way that simplifies end-of-life management.

   Other barriers identified by the participants included regulatory discrepancies between local and state authorities that cause confusion and limit opportunities for reuse of components and assets, or create obstacles to asset transportation between the points of generation and refurbishment or recycling (such as across state lines). Barriers also exist with respect to the testing required to characterize materials as non-hazardous or hazardous for EoL management and disposition. In each case, working with stakeholders throughout the value chain could allow identification of opportunities to reduce regulatory burdens, improve product design and ease of repair or reuse, increase transportability, and decrease waste generation at EoL.

[1] Lacy, Peter, Jessica Long, and Wesley Spindler (2020). The Circular Economy Handbook. *Palgrave Macmillan.*

Session 2 – Federal and State Perspectives on End-of-Life Challenges for Renewables and Batteries

The speakers who participated in the regulatory panel represented state and federal entities that research, structure, and enforce renewable energy and battery storage EoL regulations. They highlighted opportunities and challenges from the perspective of current and potential regulations. They drew parallels with other industries that have been challenged with incorporating sustainability and circularity in the life cycle of products and highlighted the need for regulations to reduce barriers and encourage circularity.

Panelists:

- Taylor Curtis, Esq., *Legal and Regulatory Analyst, National Renewable Energy Laboratory (NREL)*
  - Ms. Curtis shared that a circular economy for energy materials is one of three critical NREL objectives, and NREL is working in part to minimize risk and uncertainty for renewable energy and battery storage systems asset owners. She gave examples of existing barriers to product reuse, including interconnection, fire, building, and electrical regulations. She mentioned barriers to recycling that included solid and hazardous waste laws and regulations, hazardous materials transport regulations, and hazardous waste export regulations. Ms. Curtis also highlighted individual states that have passed, or are considering passing, regulations related to end-of-life management of renewable energy and/or battery materials.

Table 2-1
Examples of Reuse, Recycling, and Disposal Regulatory Considerations

Interconnection Regulations	**Solid and Hazardous Waste Laws & Regulations**
Fire and Building Regulations	**Hazardous Materials Transport Regulations**
Electrical Regulations	**Hazardous Waste Export Regulations**
Industry Certification Standards	**Penalties for Non-Compliance**

- Matt Henigan, *Deputy Director, CalRecycle*
  - Mr. Henigan opened with the idea that those working to improve sustainability and transition energy fleets as quickly as possible may not consider the EoL ramifications of newly deployed technologies. This increases the possibility of unintended consequences, which could require additional regulation or new public policies to resolve. He highlighted the opportunities to learn from other industries regarding material reuse and recycling, in particular the consumer electronics industry. Mr. Henigan illustrated California's system to collect a fee from consumers to offset the cost of material collection and recycling when products reach EoL and discussed newer Extended Producer Responsibility (EPR) programs that cover the cost of recycling consumer products such as paint, carpet, and mattresses. California provides state EPR checklists to assist industry with creating new EPR programs.

- Hanjiro Ambrose, *Staff, California Air Resources Board*
  - Mr. Ambrose opened with the idea that responsible EoL management for lithium ion batteries will require efficient recycling, recovery, and reuse of critical minerals, such as lithium and cobalt, to minimize lifecycle environmental impacts and burdens to local communities across the globe from extractive processes. He discussed how improving EoL management options starts with building better batteries that are more durable, use responsibly sourced materials, are designed for recycling, and eventually contain increased quantities of recycled materials. Regulatory schemes that reduce barriers and promote efficient recycling are also a need. Mr. Ambrose highlighted potential regulations and programs under consideration in California to increase battery life and improve monitoring and data sharing of battery health. These actions are intended to provide necessary information to support battery reuse or second life. Several interagency working groups exist in the state that are investigating methods to remove barriers and promote recycling.

Key Learnings

EPRI's David Hunter opened this session by asking the question, *"What regulations are going to drive how companies should dispose of, reuse, or recycle batteries or renewables?"* There are a wide range of efforts underway to work with state and local regulators to help reduce uncertainty, lower costs, and improve options for creating circularity, though currently there is little regulatory consideration at the federal level for renewable energy materials. Some states are evaluating requirements for EPR or manufacturer takeback, and how to leverage existing infrastructure to increase the amount of materials entering the recycling stream. Electrical, fire, and other local regulations that may limit reuse opportunities for EoL renewable energy and battery energy storage materials are also being reviewed. Figure 2-2 provides the current status of solar PV module and lithium ion battery regulatory consideration in the US.

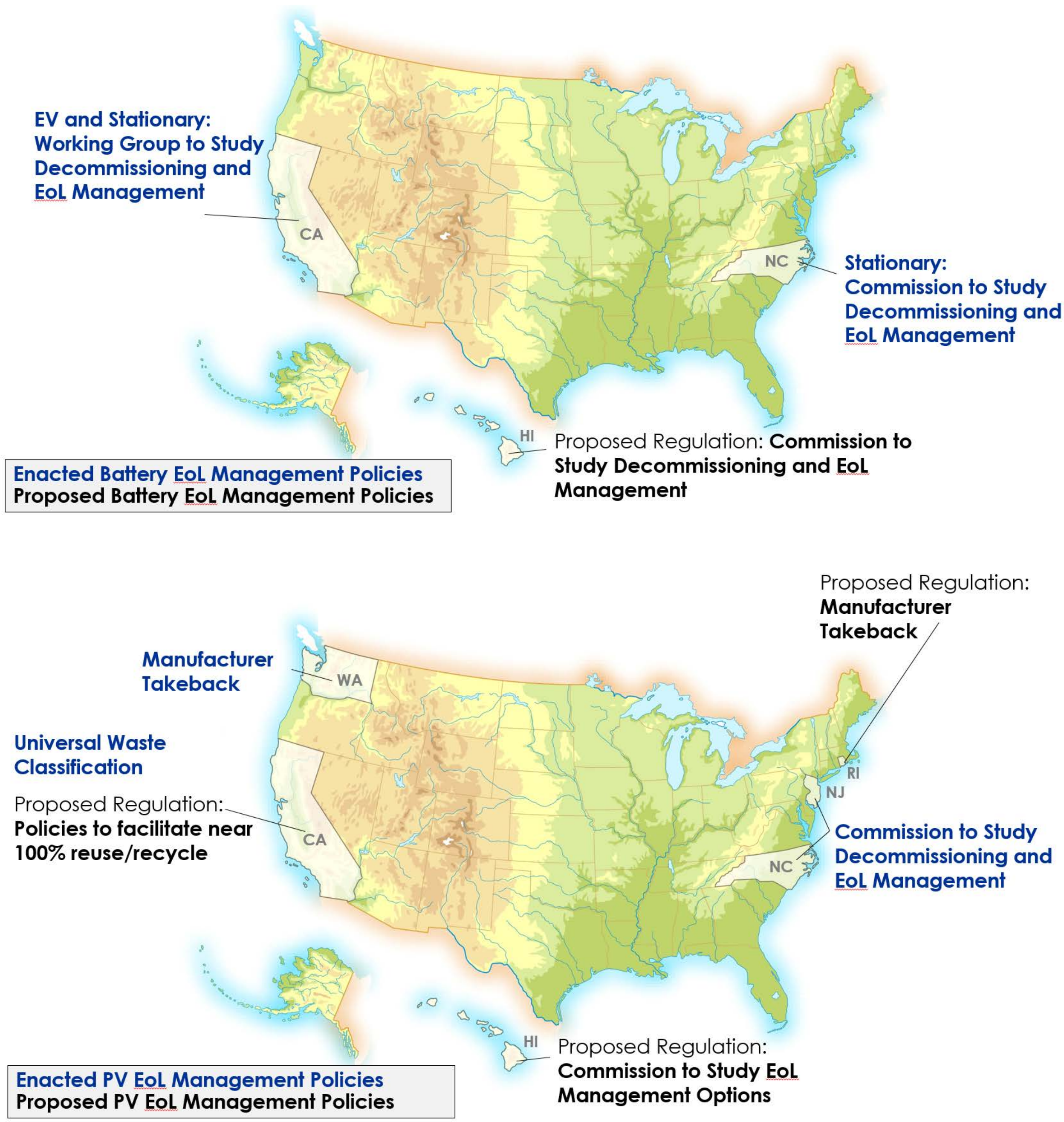

Figure 2-2
March 2021 Summary of Enacted and Pending Legislation for Lithium Ion Battery and Solar PV Module Reuse and EoL Regulations

1. *Learn from other industries that have improved circularity*

   The panelists discussed several methods that have been used to encourage reuse, recycling, reclamation, and circularity in other industries. In the United States, regulations for EPR have been used for the tire, paint, mattresses, and consumer electronics industries to encourage designs with longer life expectancy and improved recyclability and reclamation. Increased industry standardization of both product and facility design, as well as equipment composition and specifications, were highlighted as opportunities to improve the practicality of reuse, reclamation, and recycling. Another option being considered is point of purchase fees to cover EoL costs. This raises prices for consumers, and thus incentivizes manufacturers to find more cost-efficient reuse or recycling options to lower the upfront cost paid by purchasers. It is beneficial to stakeholders throughout the value chain to work with regulators early in the development and deployment of new technologies to enact regulations that promote extended life, reuse, reclamation, and recycling. Less proactive management of EoL issues for other technologies and waste products has in the past resulted in regulations that were more restrictive with little focus on encouraging circularity.

While the details of dismantling, materials of value, and opportunities for reuse applications vary by technology, state agencies and other jurisdictions, recyclers and waste management companies are already applying lessons learned from their experiences with e-waste, cathode ray tube displays, and other technologies. In fact, e-waste and glass recyclers were the first entities to recycle solar PV modules. The high collection and recycling rates for lead-acid and nickel-cadmium batteries are already serving as a long-term goal for lithium ion batteries. Learning from other industries informs estimates of reclamation costs or the salvage value of the recovered materials, as well as identification of markets where the recovered materials could be cost-competitive with virgin resources.

2. *Develop and enact regulations that incentivize circularity*

   The panelists agreed that regulations must encourage circularity rather than unintentionally create barriers for product or material reuse. Thus, existing regulations, codes, standards, and guidelines, as well as those under development, should be carefully reviewed to understand the implications. Several examples were used to highlight instances where local, state, or federal regulations are currently not supportive of reuse, recycling, and reclamation of renewable and battery materials. For example, electrical interconnection and fire codes restrict reuse of earlier generation solar modules as they do not meet current code specifications. Additionally, some regulations treat disposal and recycling as equivalent activities. Multi-agency working groups composed of local, state, and federal government representatives and stakeholders experienced with all aspects of EoL management are needed to identify where regulations may be causing uncertainty in the market or acting as direct barriers to reuse or recycling. The most effective policies would protect human health and the environment while removing specific requirements that may inhibit second life or circular economy uses.

   Specific actions that could be taken to promote circularity for renewable energy and battery storage assets include the following:

   - Enacting regulations that treat recycling and disposal as different activities;
   - Incentivizing material reuse and recycling to make it more cost effective than disposal;
   - Requiring more durable, longer-lived products that contain responsibly sourced materials and are designed for recycling;
   - Requiring recycled content, which potentially increases over time;
   - Reducing barriers for siting of collection and recycling facilities; and
   - Developing programs to cover the cost of recycling at the point of purchase, ensuring that there is an incentive for material collection and reclamation.

Session 3 – Technology Solutions and Research

The speakers who participated in the final panel represented companies that are actively engaged in research and development for extending the life of, reusing, and recycling renewable energy and battery storage materials. Several panelists confirmed that recycling effectiveness and product purity are a matter of cost and volume of the EoL material stream. To recycle at the levels necessary to replace significant amounts of raw material extraction, an entire economy around recycling must first be established. This panel reiterated points made earlier that the eventual material fate and costs must be considered at the design or project development stage; this could be facilitated by establishing fees at the point of purchase. Panelists said this approach could result in recyclable products being better positioned to compete in the market. Several circular economy opportunities were highlighted, including (1) the development of effective methodologies to extend product lifetimes, (2) refinement of processes to upgrade recovered and recycled materials such that they are chemically equivalent to virgin materials, and (3) policy or regulatory options that encourage reuse of end-of-first-life products and use of recycled or recovered materials, highlighting the potential for re-entering reusable materials into manufacturing as shown in Figure 2-3.

Panelists:

- Chris Howell, *Senior Director, Recycling Operations, Veolia*
  - Mr. Howell highlighted Veolia's new fiberglass recycling technology that shreds wind turbine blades for use in cement production, developed in conjunction with GE Renewables. He also pointed out that due to production tax credits and improvements in efficiency, many wind turbine blades (WTB) within the US currently have a lifespan of 8 to 10 years rather than the 20 to 25 years estimated when the assets were originally installed.
- Tommy McGuire, *President, Echo Environmental*
  - Mr. McGuire provided an overview of Echo Environmental and its path from a single-commodity recycler of electronic waste to a company that has greatly expanded their focus to include renewable energy materials. He discussed how Echo has developed a proprietary process to fully recycle solar PV and is looking for opportunities to create economies of scale for recycling.
- Hugo Leduc, *Senior Electrochemistry Data Scientist, ReJoule*
  - Mr. Leduc discussed the importance of battery state of health (SOH) and how these data can be critical to finding second life uses for batteries. Knowing SOH is also crucial to developing management systems that minimize battery degradation during second life uses that may be very different from that of the first life. ReJoule is working to develop fast, accurate, cost-effective SOH diagnostic tests that will allow management of battery degradation during second life applications while reducing the cost of second life batteries by 30% compared to first life batteries.
- Ben Lyon, *Vice President Business Development, RePurpose*
  - Mr. Lyons described the core business of RePurpose as converting EoL electric vehicle batteries for use in stationary energy storage applications. This takes advantage of the remaining capacity of the batteries after the end of their first life. RePurpose also uses SOH testing to estimate remaining battery life, then applies proprietary battery

management systems to control degradation. He provided two case studies where second-life Nissan Leaf batteries were used in stationary energy storage applications for an active winery and for a fresh produce market.

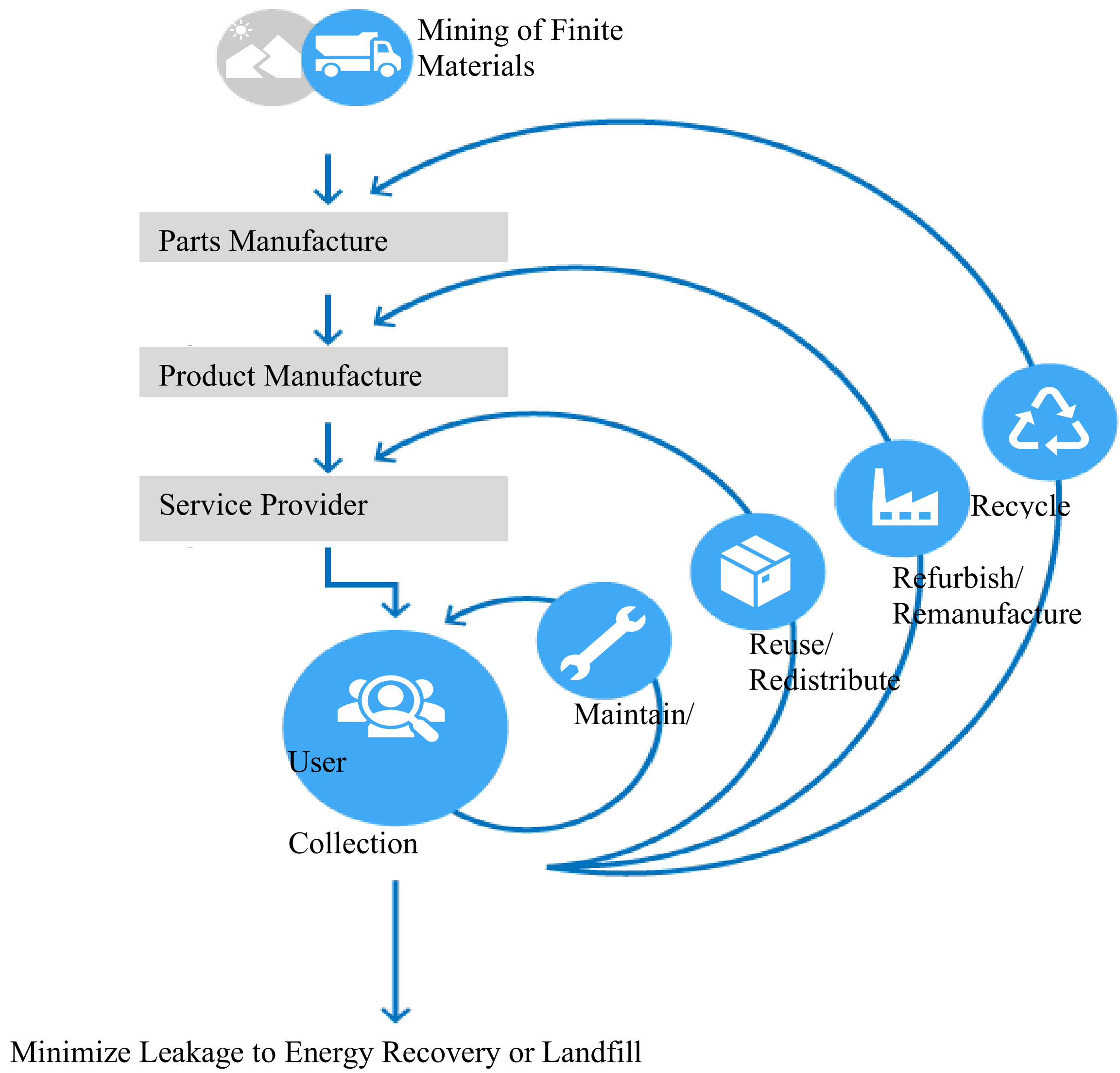

Figure 2-3
Circular Economies Re-enter Usable Materials Into Manufacturing

Key Learnings

There is extensive research underway by academia, government laboratories, and private companies to advance reuse, recycling, and reclamation technologies for renewable energy and battery storage systems, some of which were discussed during this session. Panelists highlighted opportunities for extending the life of products, opportunities for second life uses of batteries, and developing recycling processes that can more efficiently and cost-effectively recover usable material. Panelists anticipate that regulatory and policy action may be needed to encourage circularity in the industry, and to encourage reuse and recycling over landfilling.

1. *Make the second life as valuable as the first life*

   One path to increase second life material value is to analyze the life cycle of the products in which the second life materials are used to replace virgin materials and calculate the value of replacing the virgin materials. This includes the direct cost of the virgin materials, and also potentially includes savings in terms of carbon footprint for virgin material production and transport, environmental impacts avoided through reductions in virgin material production, and social impacts to regions where the virgin materials are produced. There are also benefits to increasing domestic recycling and reuse related to the increased control it gives producers and users over the material and component supply, and improves the ability for supply chains to confirm that the materials are ethically and sustainably sourced.

   An example of second life value presented by Chris Howell is the use of recycled wind turbine blades for use in cement production. In his calculation, not only does recycling the blades curtail disposal in a landfill, each 7-ton blade recycled replaces 4.6 tons of raw materials, reducing greenhouse gas emissions by 27% and water consumption by 13% compared to traditional cement production. Second life uses that prioritize refurbishing or reusing without material recycling or reclamation provide the highest value for these materials, while avoiding material loss or downcycling. Ben Lyon showed how repurposing electric vehicle batteries that no longer meet the operating requirements into stationary energy storage systems can provide electrical system stability for grocery stores and wineries, allowing operations to continue during grid outages and avoiding the loss of products worth potentially hundreds of thousands of dollars.

   Another factor that could increase the value of second life materials is the provision of regulatory or tax incentives that would encourage second life uses. Application of equal monetary incentives for first life products and second life materials is another method. For example, currently tax incentives and rebates available for first life products are not extended to second life products, making them less attractive to end users. Other incentives and regulations that currently provide a bias for first life materials, or prohibit second life material usage, can be assessed for improvements. An example is the current practice of landfilling EoL solar PV materials in many areas because the cost of landfilling is lower than recycling, and regulations either do not incentivize or act as barriers to second life uses.

   Products developed from recycled materials could also benefit from improved branding to enhance the perception of second life material value to the customer. Increasing the perceived value may provide an expectation from the public that companies will find ways to use second life materials, and thus potentially encourage manufacturing innovations to find additional uses for recycled or recovered materials.

2. *Higher EoL volumes are needed to expand services and lower costs*

   Most existing renewable energy facilities are less than 10 years old and will not reach the projected EoL for another 10 to 15 years. Individual components (e.g., battery modules or racks; PV modules) may require, or benefit from, replacement before the end of the facility life. The EoL equipment streams undergoing recycling and reclamation at this time are primarily composed of manufacturing scrap, decommissioned ‘early adoption’ systems that have reached natural end of life, and products that fall under warranty defect, are damaged, or have failed prematurely. Current EoL volumes do not yet justify development of dedicated collection and reuse/recycling infrastructure and customized processing (e.g., a dedicated PV module recycling line vs. batches of modules run in a glass recycling facility). However, EoL volumes are anticipated to increase in future years through both repowering and facility decommissioning as additional assets are deployed and age. As EoL volumes grow, economies of scale will allow the collection, transportation, and processing of the materials to mature, subsequently lowering costs. In the meantime, leveraging existing recycling infrastructure can increase the total EoL volumes being processed on existing lines and the amount of material recovered. One example discussed was the combination of solar PV waste with consumer electronic waste.

3
SUMMARY

The power sector is rapidly adding renewable energy and battery storage resources to meet decarbonization goals—and in the process generating new types of EoL materials. While the volumes of battery energy storage, solar PV, and wind turbine blades reaching EoL are currently small, they are expected to grow dramatically as new and existing systems complete their service lifetimes and are decommissioned. Circular economy concepts promote efficient use of resources that can improve material security as well as environmental, social, and economic outcomes. The application of these practices to battery and renewable EoL materials is at an early stage, with many issues currently unresolved.

The objectives of this Washington Seminar were (1) to identify opportunities and challenges facing the power sector as companies transition to managing end-of-life of a wider range and amount of clean energy technologies in their portfolios, (2) to provide federal and state perspectives on relevant regulatory and policy approaches that are under consideration or have been implemented, and (3) to offer research reviews of technology advances with the potential to facilitate this transition. The diverse group of renewable energy and battery energy storage stakeholders participating in the panels provided insights on the journey to circular economies, such as:

1. Prioritization of extended life and second life requires early consideration at the component and system design phase;
2. Complete value assessments must include a range of second life and circular economy products and materials; and
3. Regulations and incentives can enhance, reduce or prohibit recycling, reuse, and other circular economy actions; effects should be identified and adjusted accordingly.

These insights recurred in discussions on each link of the material value chain, indicating that collaborative, bidirectional partnerships can and should be used to identify and leverage opportunities while working to remove barriers for circular economy participation for solar PV, wind turbine blade, and battery energy storage technologies.

The agenda, panelist presentations, audio recording, and additional EPRI resources from the March 2020 Washington Seminar event are available at www.epri.com/pages/sa/washington-seminar.

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