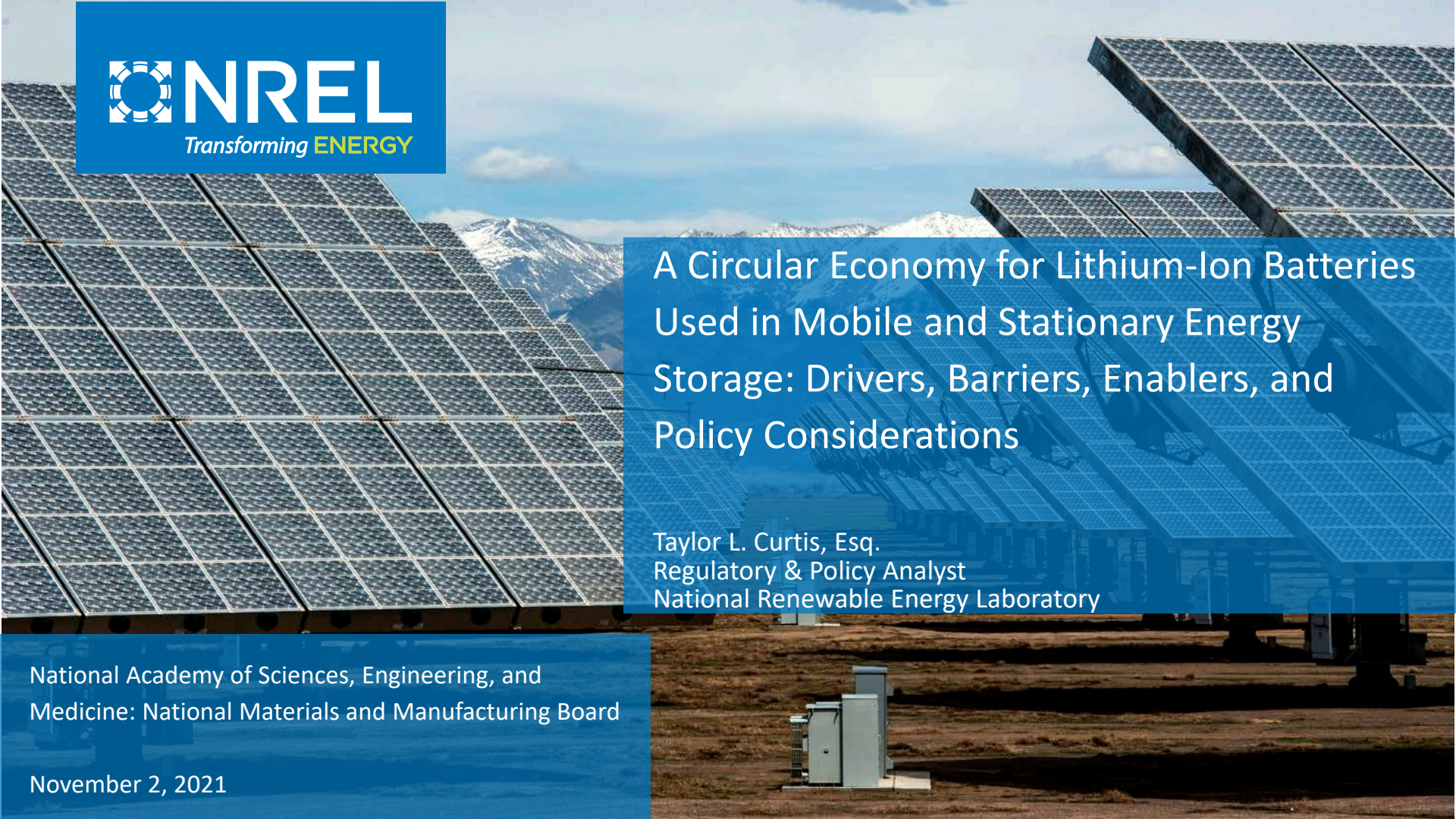

A Circular Economy for Lithium-Ion Batteries Used in Mobile and Stationary Energy Storage: Drivers, Barriers, Enablers, and Policy Considerations

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Management Options for Retired Lithium-Ion Batteries (LiBs) Used in Mobile and Stationary Battery Energy Storage (BES)

Reuse

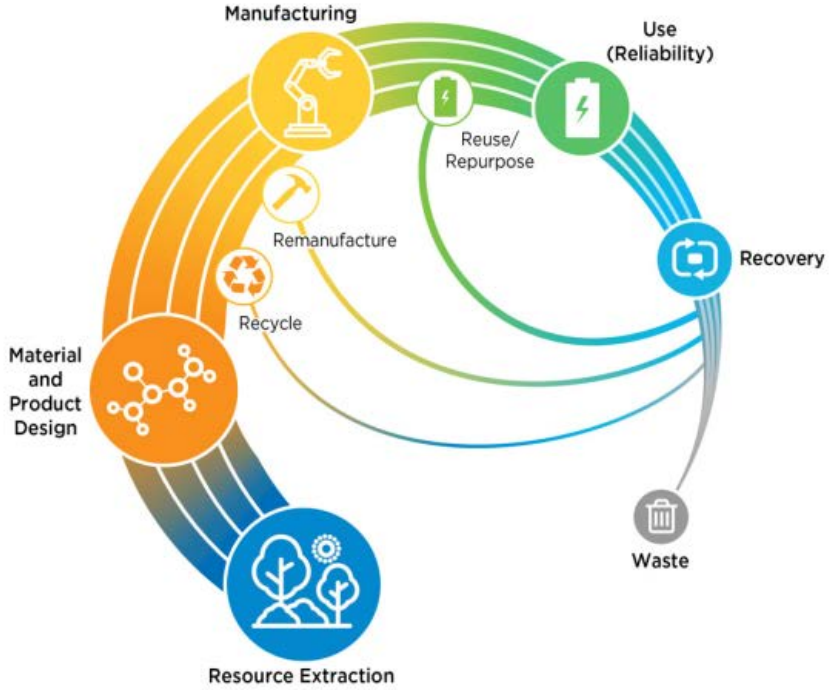
- Retired EV LiB modules and cells may be refurbished/modified for reuse in other mobile BES systems (e.g., forklifts) or for reuse in stationary BES applications

Recycle

- Recovered materials can be used to manufacture new batteries or be sold into commodity markets

Storage

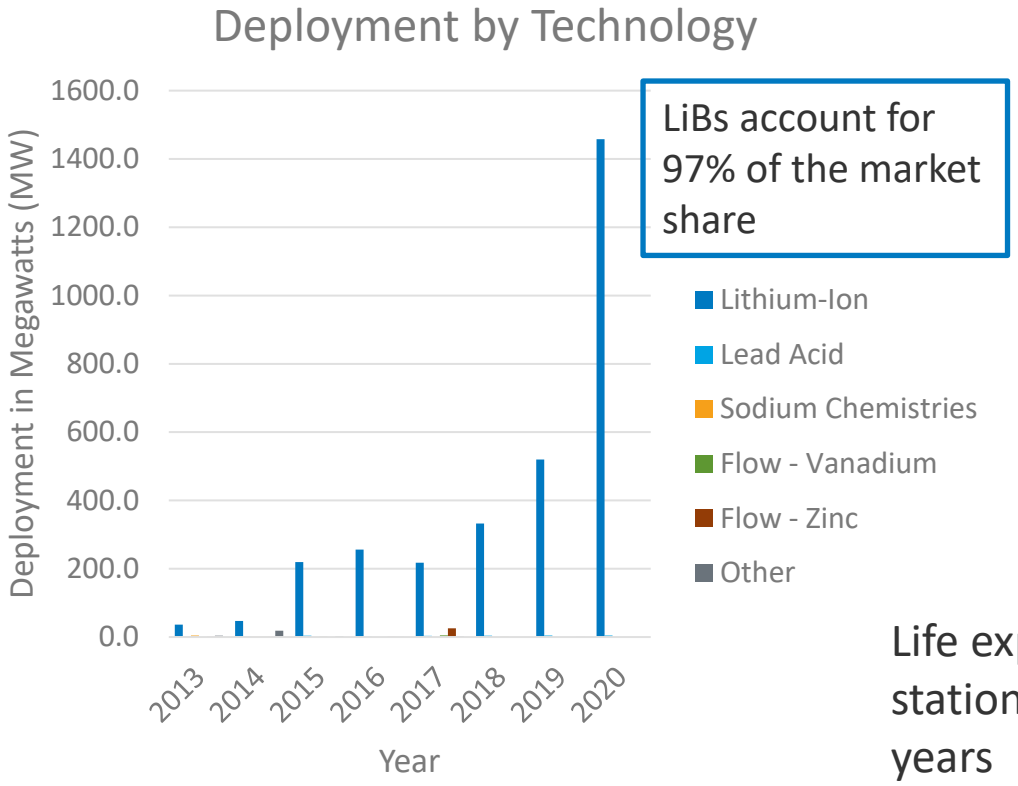
Disposal



Source: Curtis et al., 2021

Battery Energy Storage (BES) Deployment, Projections, and Retirement Trends in the United States

U.S. Stationary BES Deployment and Projections



LiBs account for 97% of the market share

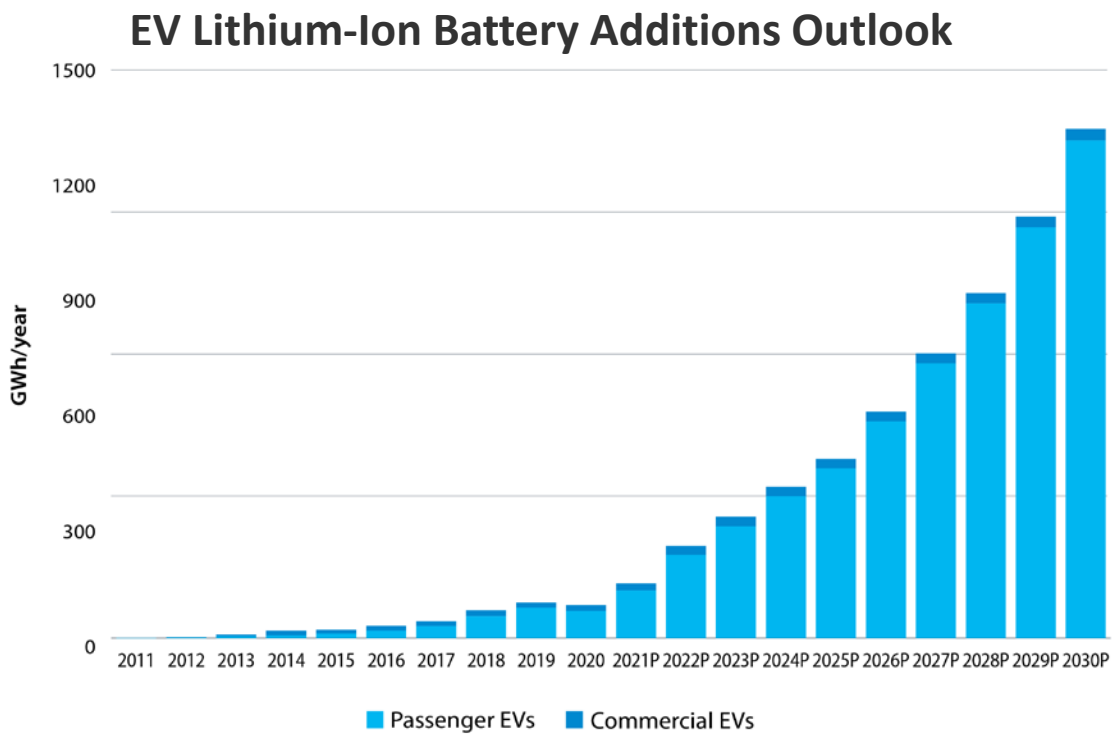
Total installed large-scale stationary BES is expected to increase almost 10-fold from 2021 to 2025

An additional **30 plus GW of stationary BES** in the U.S.

Life expectancy estimates for large-format stationary LiBs for BES range from 7 to 15 years

Sources: Curtis et al. 2021; Wood MacKenzie and ESA 2021

U.S. Electric Vehicle (EV) LiB Deployment and Projections



Passenger EVs are expected to reach **16 million units on U.S. roads by 2030 and 46 million by 2025**

Volume of LiBs that have reached the end of their utility could reach **2 million units (4 million Mt) annually by 2040** in the U.S.

Sources: Curtis et al. 2021; BloombergNEF. 2020. Electric Vehicle Outlook 2020. May 19, 2020

U.S. Imports Raw Materials to Meet Domestic Demand

70% of cell capacity and approximately 87% of battery packs for light duty EVs are U.S. made

Telsa and Panasonic lead battery manufacturing for stationary batteries

The U.S. is **heavily reliant on raw material imports for domestic manufacturing**

The U.S. Department of Interior determined that **cobalt, graphite, lithium, and manganese are critical materials** essential to economic and national security

The World Bank expects the demand for **graphite, lithium and cobalt to increase by nearly 500% by 2050**

The U.S. Geological Survey and U.S. Department of Commerce found that **cobalt was among the materials at the highest risk of supply chain disruption**

NREL analysts predict **a shortage of nickel within 3-7 years if current trends persist – increase of nickel content in battery cathode design to replace cobalt**

Sources: Curtis et al. 2021; Wood MacKenzie and ESA 2021

Retired LiB Management Trends

Today, anecdotal evidence suggests there are low volumes of retired LiBs used in mobile and stationary BES in the U.S., however first-generation EV batteries are starting to reach end-of-life and the future of the large-format LiB waste stream is becoming more certain

Reuse of large-format LiBs is not at commercial scale and to date consists of only a handful of U.S.-led pilot projects

The accessibility and cost of large-format LiB recycling is often overshadowed by cheaper and more accessible storage and disposal options

Evidence suggests that less than 5% of LiBs from EVs in the U.S. are sent to recyclers

Sources: Curtis et al., 2021; Kumagai 2021; Warren 2020; Gerstein 2020; Steward et al., 2019; Collins 2019; Kelleher Environmental 2019; NREL 2019; Salim et al., 2019; DTSC 2019; CPUC 2019; Jacoby 2019

Drivers, Barriers, and Enablers to a Circular Economy for LiBs

Drivers of a Circular Economy for LiBs

Economic Driver	Description
Cost savings and increased profits	Decrease manufacturing costs and achieve additional revenue streams and tax benefits
Enhanced competitiveness	Increase a business's green or environmentally responsible image and increase consumer trust
New and expanded market and employment opportunities	Provide opportunities for new and expanded markets, and job creation
Environmental Driver	**Description**
Reduced negative environmental impacts	Reduce waste, the generation of greenhouse gases and other environmental pollutants, and the total energy required to mine, transport, refine, and manufacture products
Reduced resource constraints	Conserve high-value materials, prevent resource constraints, and reduce import demand of raw materials

Source: Curtis et al., 2021

Barriers to a Circular Economy for LiBs

Barrier	Description
Current technology, infrastructure, and processes	Technology, infrastructure, and processes are not optimized for efficient cost-effective refurbishment for reuse or recycling of LiBs
Lack of critical information and data	Limited information and data regarding: the value of, and markets for, reused LiBs and recovered LiB materials; the volume and composition of retired LiBs; the condition and characteristics of retired LiBs; quality, performance, reliability, safety, and technical viability of repurposed LiBs; refurbishment and recycling technology, services, processes; costs; and infrastructure needs
Unclear, complex, and varied laws and regulations	Laws and regulations applicable to reuse and recycling of LiBs that are unclear, complex, vary by jurisdiction, and often require compliance with stringent handling, storage, transport, treatment, recycling and disposal requirements that are subject to civil and criminal liability for non-compliance
Lack of economic motivation	Limited economic motivation or incentive to enable collection, transport, reuse or recycling of LiBs, or to enable the design for durability, reuse and recycling
Low market confidence in refurbished and reused LiBs	Inadequate consumer confidence in repurposed LiBs to support secondary markets

Source: Curtis et al. 2021

Enablers for a Circular Economy for LiBs

Enabler	Description
Research, development, and analysis	The following could reduce uncertainty and investment risk, inform market opportunities, and increase consumer confidence: R&D and analysis regarding the value of and markets for reused LiBs and recovered LiB materials; volume, condition and composition of retired LiBs; circular business models; battery design; refurbishment and recycling processes, services, and technology; techno-economic analysis; and technical guidance
Publicly available information and information exchange	Information availability and exchange— between manufacturers, system owners, installers, operation and maintenance entities, third-party reuse/recycling companies, logistic companies, landfill owners/operators, repair shops, mechanics, and other BES supply chain actor—could reduce costs, market and regulatory uncertainty and risk, and increase good faith relationships between industry stakeholders
Economic incentives	Both incentives given to promote the collection, transport, reuse/recycling of LiBs, and (2) LiB design for durability and reuse/recycling could encourage innovation and private investment by making the economics of early investment more desirable
Regulation and policy	Federal and state policies could require or incentivize the collection and reuse/recycling of LiBs or restrict disposal. Clearly defined regulatory requirements could reduce uncertainty and risk associated with LiB reuse/recycling activities (e.g., regulatory requirements under RCRA). In the absence of regulation, global and national voluntary industry standards (e.g., UL 1974) and goals (e.g., durable, standardized LiB design) could enhance a company's competitiveness and provide consumer confidence in secondary market goods

Source: Curtis et al., 2021

Statutory and Regulatory Considerations for the Reuse and Recycling of LiBs

Regulatory Considerations for the Reuse of LiBs

Consideration	Description
Interconnection Regulations	State and local regulations that govern how BES systems connect to the electric grid, which may restrict the reuse of LiBs in certain grid-tied applications
Fire and Building Regulations	State and local regulations that govern the design, materials, and quality of buildings and structures that connect to stationary BES systems, which may restrict the reuse of LiBs in certain grid-tied and off-grid applications
Electrical Regulations	State and local regulations that govern electrical safety, design, installation, and inspection of BES systems and LiBs, which may restrict the reuse of LiBs in certain grid-tied and off-grid applications
Industry Certification Standards	Voluntary international industry standards that provide safety and reliability guidance for the reuse of LiBs

Source: Curtis et al., 2021

Statutory and Regulatory Considerations for the Recycling and Disposal of LiBs

Consideration	Description	Application
Solid Waste Laws and Regulations	Mandatory requirements that vary across jurisdictions, which govern the generation, handling, storage, treatment, transport, recycling, and disposal of non-hazardous solid wastes, which may include large-format LiBs accumulated or stored before recycling, or disposal and those being recycled or disposed of	Recycle, Disposal
Hazardous Waste Laws and Regulations	Mandatory requirements that vary across jurisdictions, which govern the generation, handling, storage, treatment, transport, recycling, and disposal of hazardous solid wastes, which may include large-format LiBs accumulated or stored before recycling, or disposal and those being recycled or disposed of. Hazardous waste requirements are more stringent than non-hazardous waste requirements	Recycle, Disposal
Universal Hazardous Waste Law and Regulations	Optional alternative hazardous waste requirements that vary across jurisdictions, which govern the generation, handling, storage, treatment, transport, recycling and disposal of specified types of wastes, which may include large-format LiBs accumulated or stored before recycling, or disposal and those being recycled or disposed of. Universal hazardous waste requirements are a subset of-–and are less stringent than—hazardous waste requirements, but more stringent than non-hazardous solid waste requirements	Recycle, Disposal

Source: Curtis et al., 2021

Regulatory Considerations for the Reuse, Recycling and Disposal of LiBs

Consideration	Description	Application
Hazardous Materials Transport Regulations	Mandatory federal requirements that govern U.S. interstate commerce shipping and transport of hazardous materials, which may include large-format LiBs being shipped or transported across state lines for reuse, recycling or disposal	Reuse, Recycle, Disposal
Hazardous Waste Export Regulations	Mandatory requirements that govern the export, shipping, and transport of hazardous materials to other countries, which may include large-format LiBs being exported, shipped, or transported for reuse, recycling, or disposal	Reuse, Recycle, Disposal
Penalties for Non-Compliance	Civil and criminal penalties administered for violating a jurisdiction's hazardous waste and/or hazardous materials statutes or regulations	Reuse, Recycle, Disposal

Ex. Noncompliance with any RCRA provision can result criminal penalties up $50K per violation per day, and up to 2 years in prison or both

Source: Curtis et al., 2021

LiB Reuse and End-of-Life Management Policies

Enacted Policies

- Commission to Study EV Battery Reuse and EoL Management Options
- Commission to Study Stationary Battery Reuse and EoL Management Options

Proposed (Pending) Legislation

- Commission to Study Stationary Battery Reuse and EoL Management Options

State-Led Initiatives

- Commission to Study EV and Stationary Battery Reuse and EoL Management Options

Source: Curtis et al., 2021

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Thank You

Q&A

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