Regulatory and Policy Considerations for the Reuse and End-of-Life Management of Solar and Batteries in the U.S.

Taylor L. Curtis, Esq.
Regulatory & Policy Analyst
National Renewable Energy Laboratory

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

Reuse

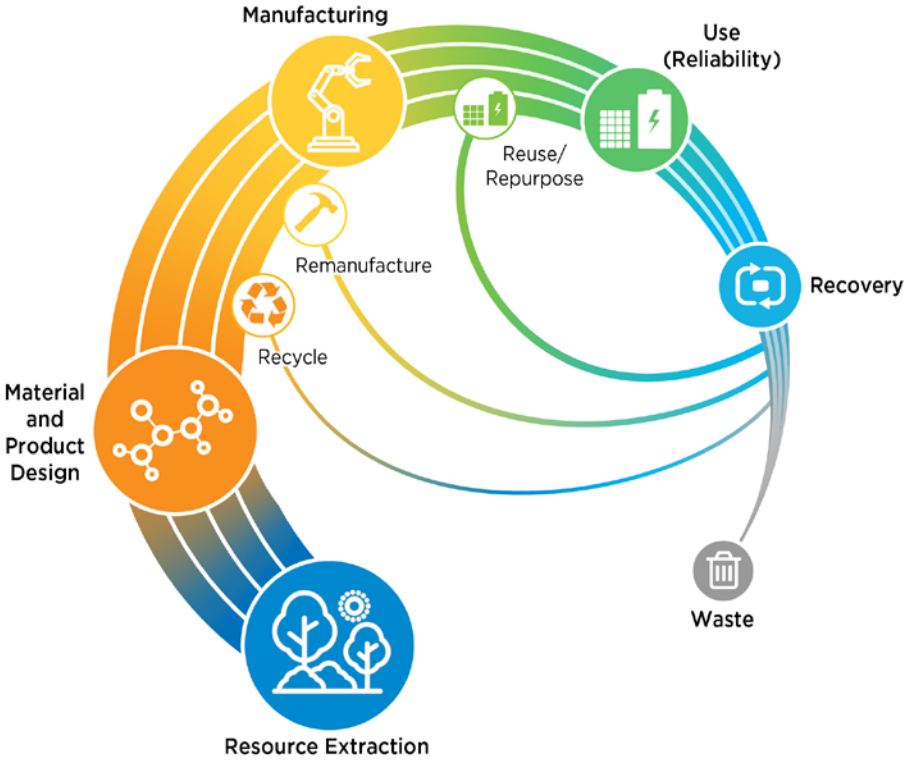
- Retired EV LiB modules and cells may be refurbished/modified for reuse in other mobile BES systems (e.g., forklifts) or for reuse in stationary BES applications
- Retired PV modules may be suited for direct reuse or be repaired for reuse in grid-tied and off-grid applications

Recycle

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

Storage

Disposal



Source: adapted from Curtis et al., 2021a; Curtis et al. 2021d

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

U.S. PV Deployment and Retirement Projections

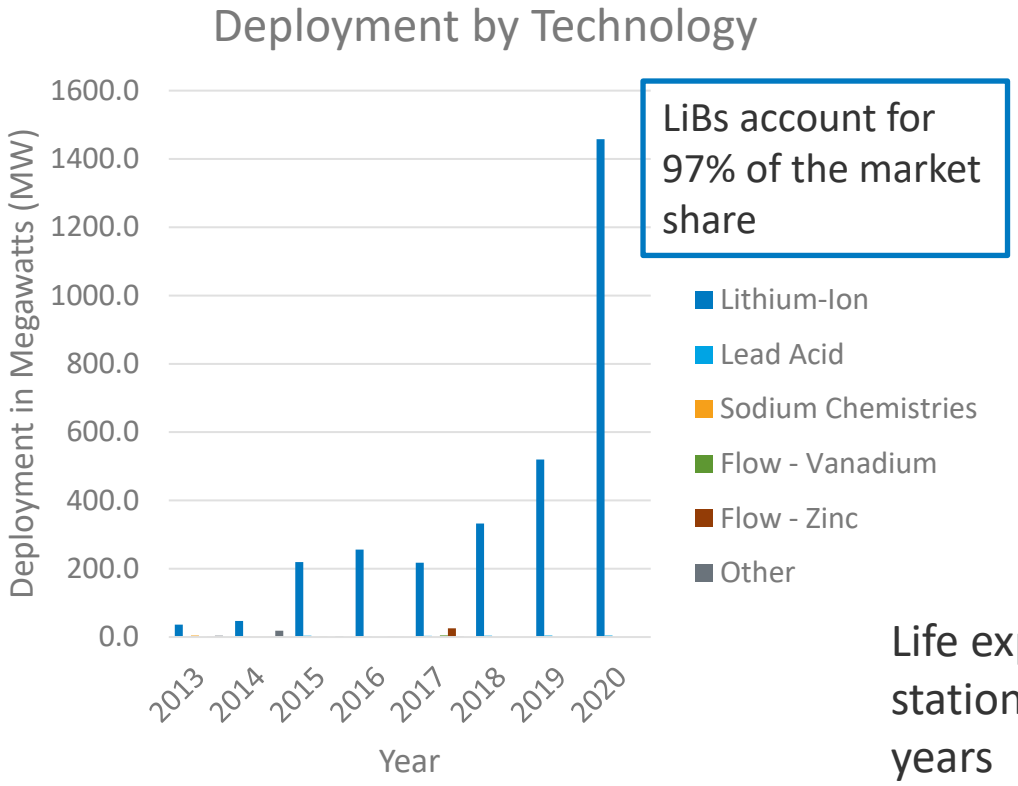
In the U.S. cumulative installed PV capacity exceeded **95 GWdc** of capacity at the **end of 2020**

If current trends persist, PV is expected to expected to grow faster than any other renewable energy sector in the U.S. and cumulative installed PV capacity **could reach 202 GW by 2025**

At approximately 80-100 metric tons (Mt) of PV modules per MW, modules installed in the U.S. (as of the end of 2020) will result in **7.6 million to 9.5 million metric tons of EoL modules**

Source: Curtis et al. 2021a; Curtis et al. 2021b; Curtis et al 2021c

U.S. Stationary BES Deployment and Projections



LiBs account for 97% of the market share

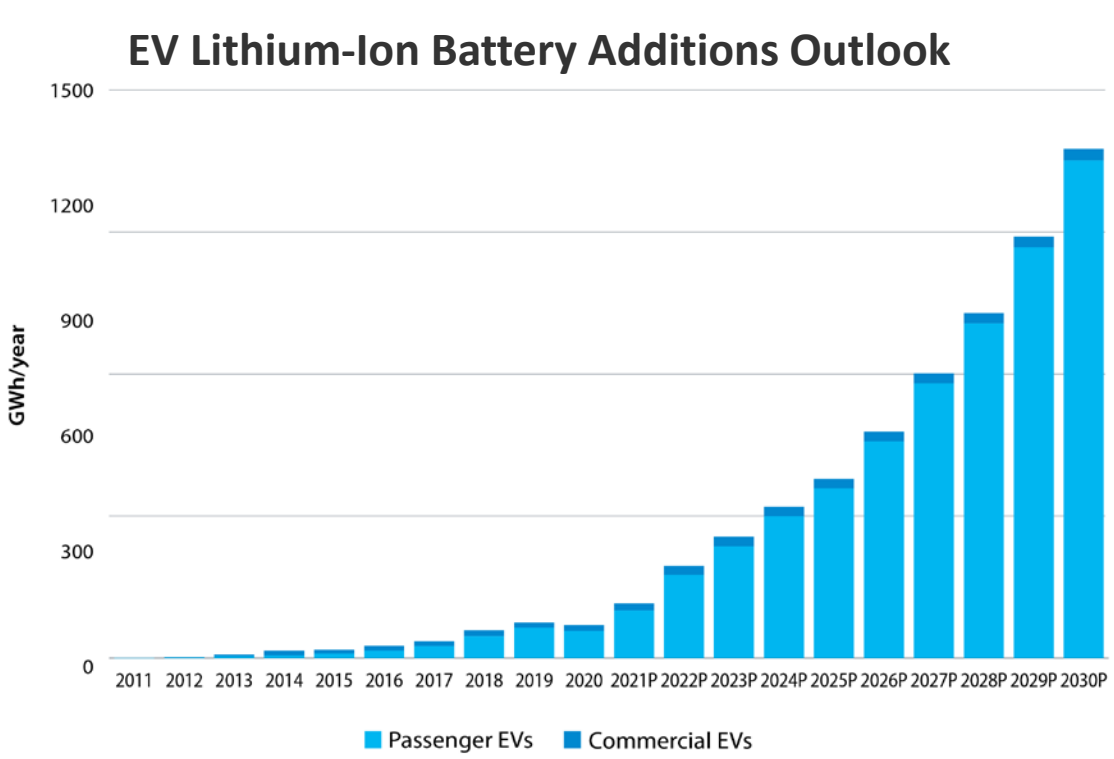
Total installed large-scale stationary BES is expected to increase almost 10-fold from 2021 to 2025

An additional **30 plus GW of stationary BES** in the U.S. by 2025

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

Source: Curtis et al. 2021d; Wood MacKenzie and ESA 2021

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



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.

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

U.S. Imports to Meet Domestic Demand

In the last decade, the **U.S. has lost 80% of its global market share** of solar-grade polysilicon, PV cells, and PV modules

In 2017, the **U.S. imported 92% of the domestic market for crystalline silicon (c-Si) and thin-film modules** and relied entirely on imported wafers to meet domestic manufacturing needs

In 2019, **U.S. manufacturers relied entirely on glass imports** to meet domestic c-Si module manufacturing needs

The U.S. is **heavily reliant on imports to meet domestic mobile and stationary BES demand.**

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

Source: Curtis et al. 2021a; Curtis et al. 2021d; Wood MacKenzie and ESA 2021

Retired PV Module Management Trends

Today, only a few PV manufacturers have a program in place to reuse or recycle retired PV modules, and only a handful of third-party companies' repair, or resale used PV modules and balance of system equipment for secondary market use

Moreover, although there is a growing number of third-party recyclers in the U.S. that accept PV modules evidence suggests that the cost of module recycling ranges from $15-45 per module, while one study found that disposal tipping fees at a nonhazardous landfill ($26/U.S. ton) can cost less than $1 per module and less than $5 per module at hazardous waste landfills ($175/U.S. ton)

Evidence suggests that less than 10% of PV modules in the U.S. are sent to recyclers

Source: Curtis et al., 2021a

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 or disposal options

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

Sources: Curtis et al., 2021d

Regulatory Considerations for the Reuse of PV Equipment and LiBs

Consideration	Description
Interconnection Regulations	State and local regulations that govern how PV systems and stationary BES systems connect to the electric grid, which may restrict the reuse of PV equipment (e.g., modules, inverters) and 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 PV systems and stationary BES systems, which may restrict the reuse of PV equipment (e.g., modules, inverters) and LiBs in certain grid-tied and off-grid applications
Electrical Regulations	State and local regulations that govern electrical safety, design, installation, and inspection of PV systems, PV equipment, BES systems and LiBs, which may restrict the reuse of PV equipment and 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 (e.g., UL 1974)

Source: Curtis et al., 2021a; Curtis et al. 2021b

Statutory and Regulatory Considerations for the Recycling and Disposal of PV Modules and 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 PV modules and 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 PV modules and 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 PV modules and 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., 2021a; Curtis et al., 2021d

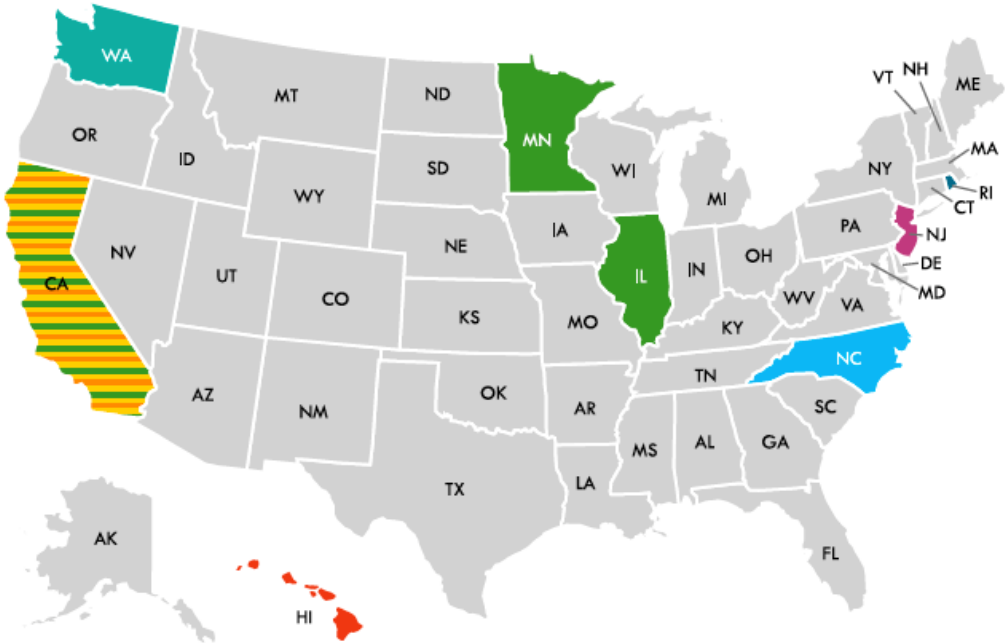
Regulatory Considerations for the Reuse, Recycling and Disposal of PV modules and LiBs

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 PV modules and 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 PV modules and 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 regulatory requirements	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., 2021a, Curtis et al., 2021d

PV Equipment Reuse and End-of-Life Management Policies



Enacted Policies

- PV Module Manufacturer Takeback
- Commission to Study PV System Decommissioning, PV Module Reuse, and PV Module EoL Management Options
- Commission to Study PV Module EoL Management Options
- PV Module Universal Waste Classification

Proposed (Pending) Legislation

- Proposed Legislation – Commission to Study PV Module Reuse and PV Module EoL Management Options
- Proposed Legislation – Commission to Study PV Module and BOS Equipment EoL Management Options
- Proposed Legislation – PV Module Manufacturer Takeback

State-Led Initiatives

- Working Group to Study PV Module and BOS Equipment Reuse and EoL Management Options

Source: Curtis et al., 2021a, Curtis et al., 2021c

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., 2021d

References

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