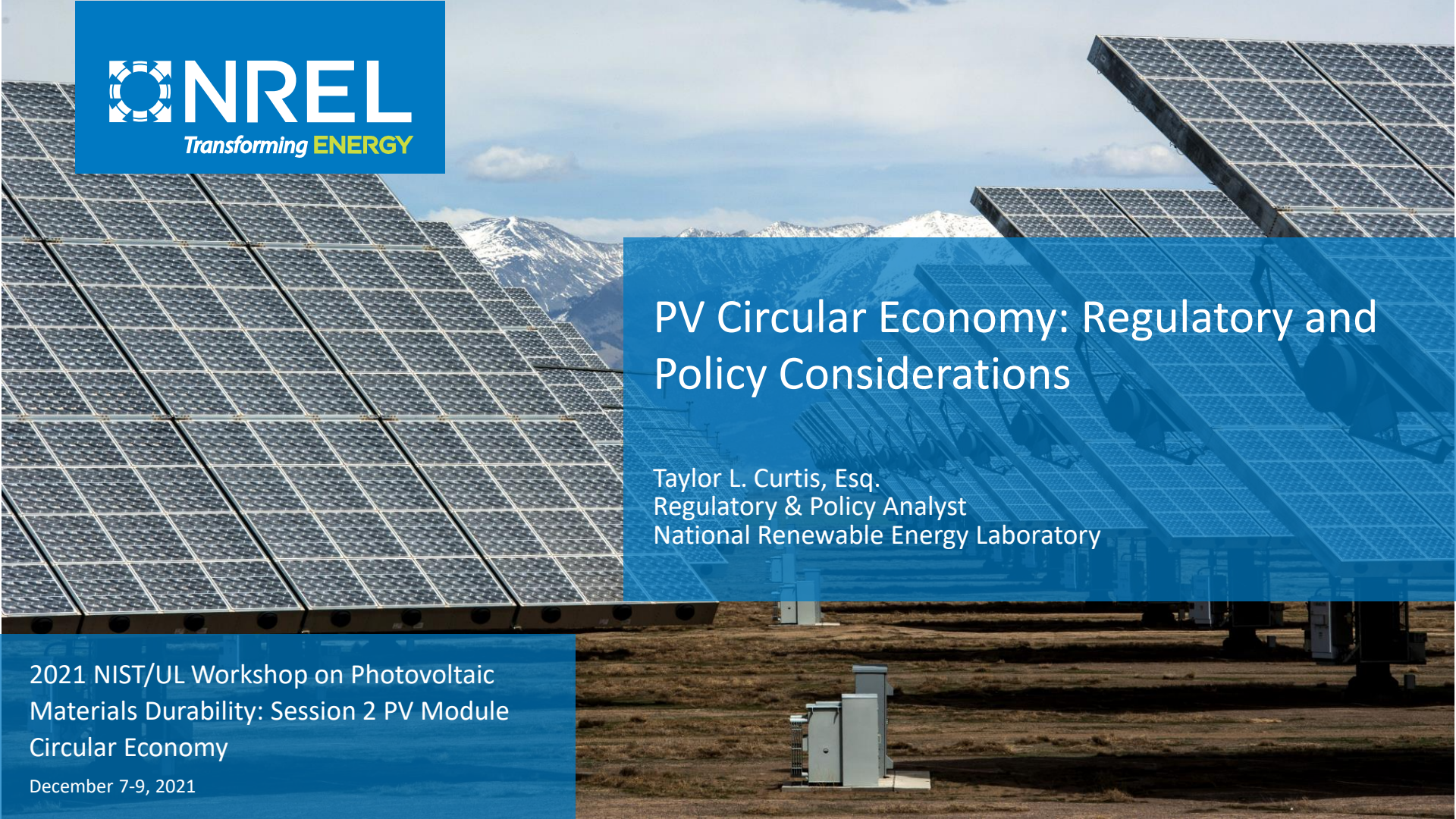

PV Circular Economy: Regulatory and Policy Considerations

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2021 NIST/UL Workshop on Photovoltaic Materials Durability: Session 2 PV Module Circular Economy

December 7-9, 2021

Management Options for Retired Solar PV Equipment

Reuse

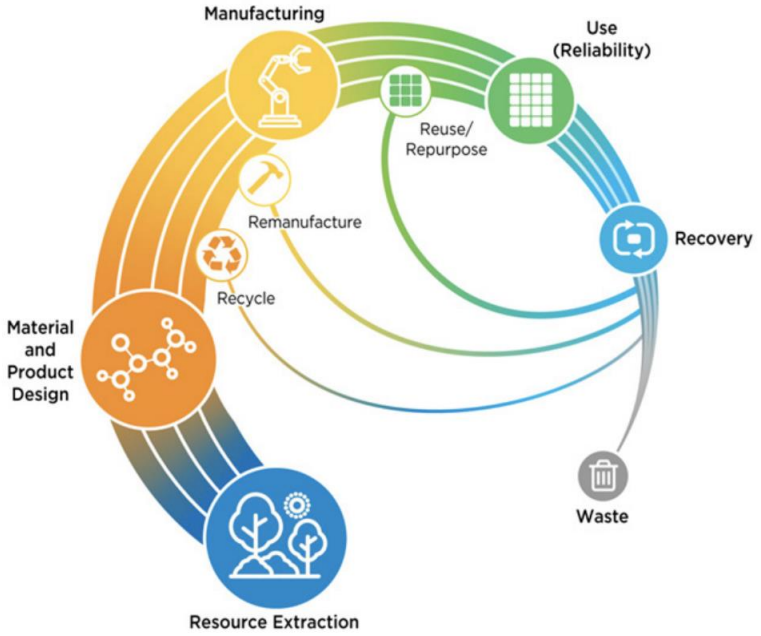
- Retired PV modules may be suited for direct reuse or be repaired for reuse in grid-tied and off-grid applications

Recycle

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

Storage

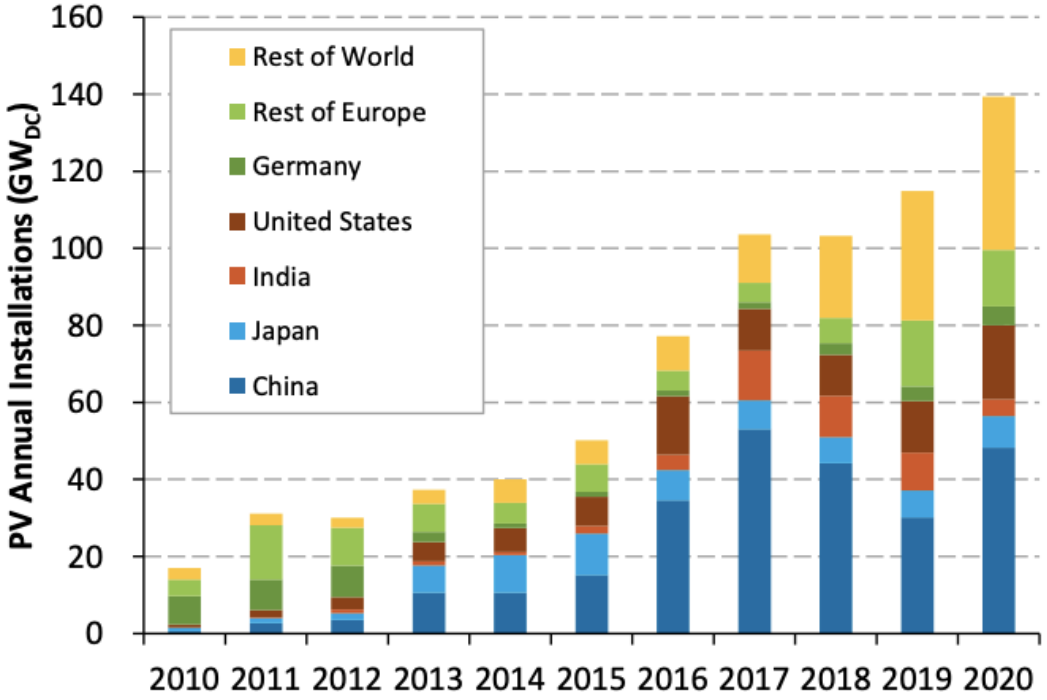
Disposal



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

Photovoltaic (PV) Solar Deployment, Projections, and Retirement Trends in the United States

Global Annual PV Capacity Additions by Country



From 2010 to 2020, global PV capacity grew from 17 GW_{dc} to 139 GW_{dc}

At the end of 2020, global PV installations reached 760 GW_{dc}

Sources: IEA, Snapshot of Global PV Markets: 2021; PVPS Snapshot 2020

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. 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

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 recycling retired PV modules, and only a handful of 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 U.S. are sent to recyclers

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

Statutory and Regulatory Considerations for the Reuse and Recycling of PV Equipment

Regulatory Considerations for the Reuse of PV Equipment

Consideration	Description
Interconnection Regulations	State and local regulations that govern how PV systems s connect to the electric grid, which may restrict the reuse of PV equipment (e.g., modules, inverters) 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, which may restrict the reuse of PV equipment (e.g., modules, inverters) 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, and PV equipment, which may restrict the reuse of PV equipment in certain grid-tied and off-grid applications

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

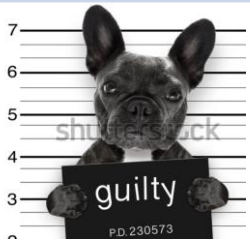
Statutory and Regulatory Considerations for the Recycling and Disposal of PV Modules

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 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 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 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

Sources: Curtis et al., 2021b; Curtis et al., 2021c

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

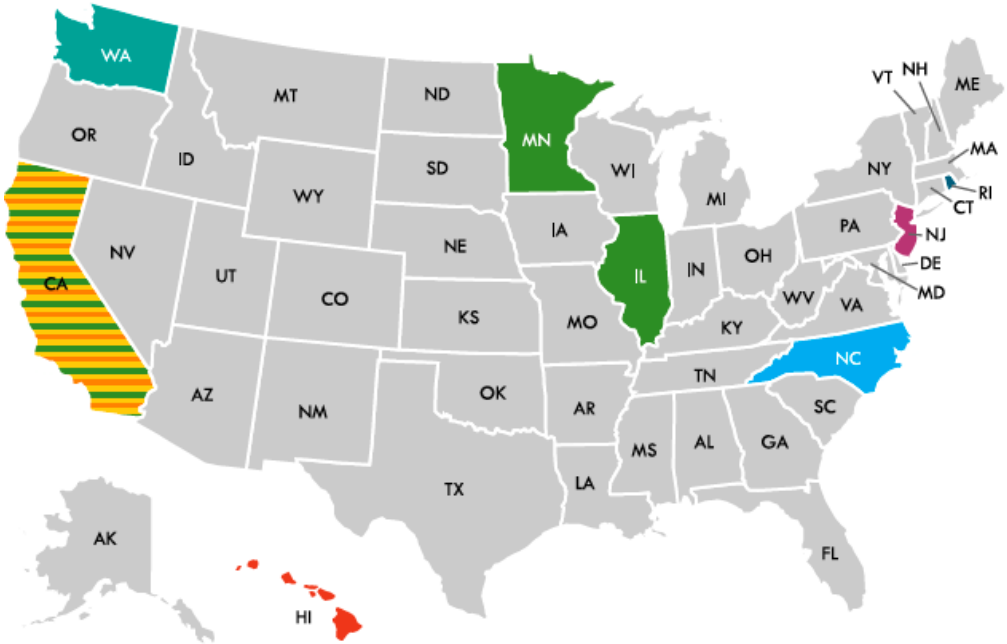
Consideration	Description	Application
Hazardous Materials Transport Regulations	Mandatory federal requirements that govern U.S. interstate commerce shipping and transport of hazardous materials, which may include PV modules being shipped or transported across state lines for reuse, recycling or disposal	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 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

Sources: Curtis et al., 2021b, Curtis et al., 2021c

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., 2021b, Curtis et al., 2021c

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