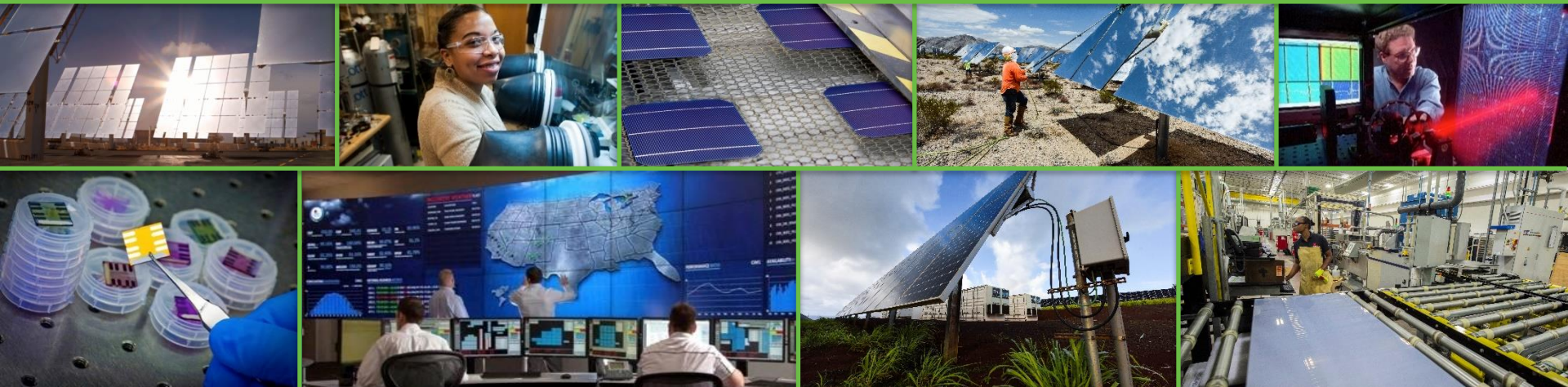


Photovoltaics End-of-Life and Recycling

Krysta Dummit, PhD, U.S. Department of Energy Solar Energy Technologies Office (SETO)

November 29, 2024

Slides courtesy of Dr. Lenny Tinker, Dr. Susan Huang, and Dr. Noreen Gentry



DOE Solar Energy Technologies Office (SETO) Overview

MISSION

We accelerate the **advancement** and **deployment of solar technology** in support of an **equitable** transition to a **decarbonized economy no later than 2050**, starting with a decarbonized power sector by 2035.

WHAT WE DO

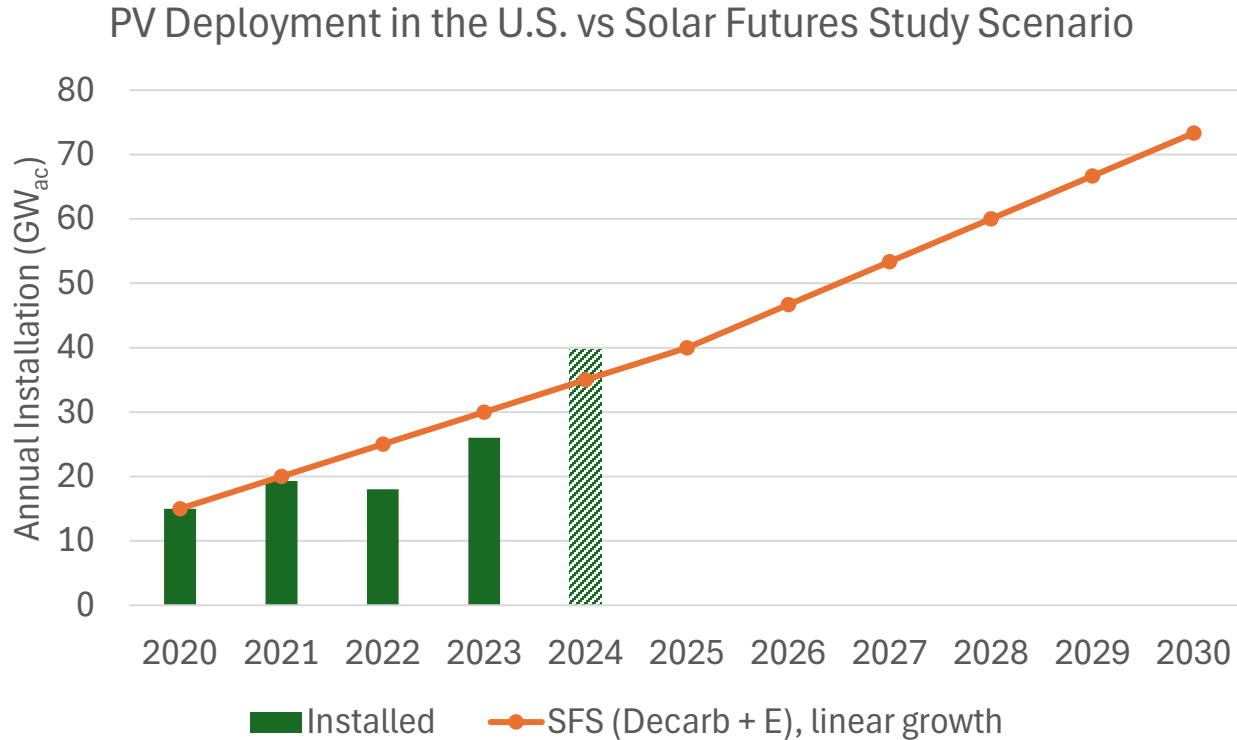
Drive innovation in technology and soft cost reduction to make solar **affordable** and **accessible** for all Americans

Enable solar to support the **reliability, resilience, and security** of the grid

Support **job growth, manufacturing, and the circular economy** in a wide range of applications



Our Goals Require a Rapid, Growing Deployment



EIA, Electric Power Monthly, Table 6.1.A. https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_6_01_a

Public Concerns About Solar Panel Waste



2017

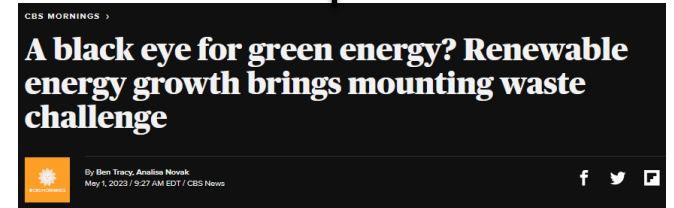


2021

2020



2023



Waste

Ecological Risk

Source: "Winter 2024 Solar Industry Update" NREL 1/25/24 [nrel.gov/docs/ty24osti/88780.pdf](https://www.nrel.gov/docs/ty24osti/88780.pdf)
CBS News (5/1/23); Environmental Progress (6/21/17); Harvard Business Review (6/18/21); Wired (8/22/20).

Public Concerns About PV Waste



KENS5 and Soler Power World



Harvard Business Review Sustainable Business Practices

KENS5 and Soler Power World



Laurent Julliard

CULTURE GEAR
Starting Toxic T...
lean energy
lar e-waste glut.

Media stories influence public perception

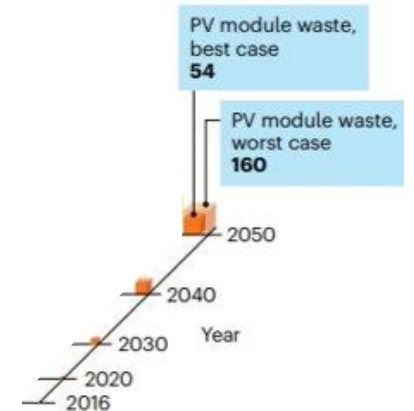
- Context, significance, and overall magnitude of impact often missing

Source: "Winter 2024 Solar Industry Update" NREL 1/25/24 [nrel.gov/docs/fy24osti/88780.pdf](https://www.nrel.gov/docs/fy24osti/88780.pdf)
CBS News (5/1/23); Environmental Progress (6/21/17); Harvard Business Review (6/1821); Wired (8/22/20).

But What About the Numbers?



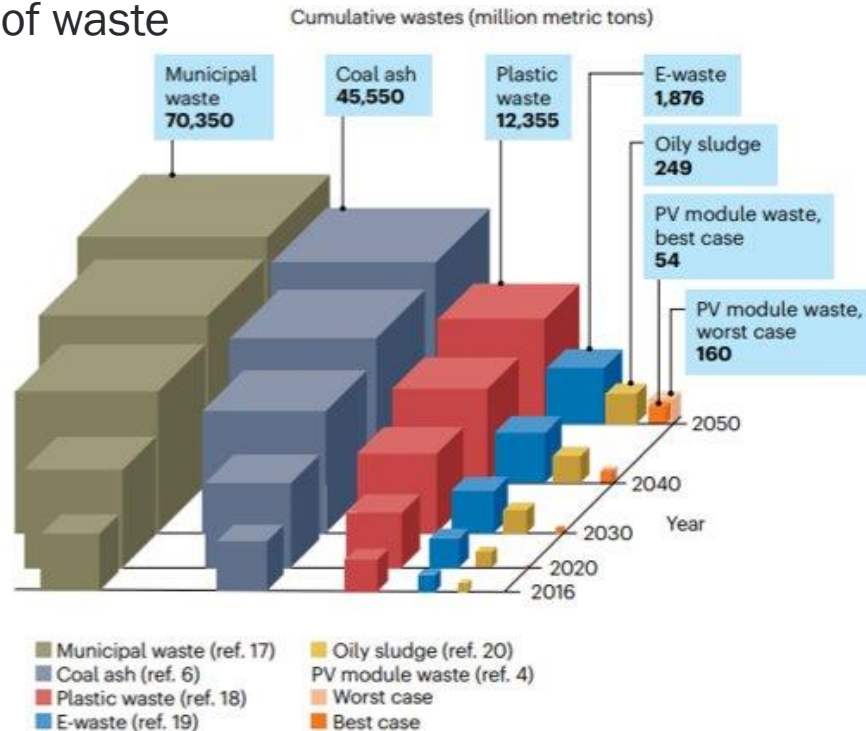
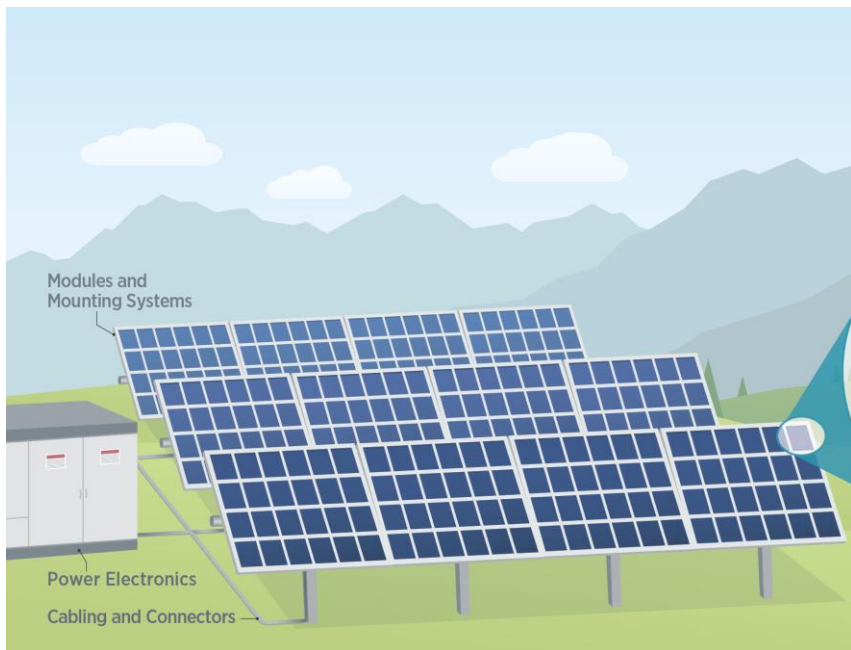
Cumulative wastes (million metric tons)



Mirlletz, H., Hieslmair, H., Ovatt, S. *et al. Nat. Phys.* **19**, 1376–1378 (2023).

But What About the Numbers?

Forward projections estimate future volumes of waste

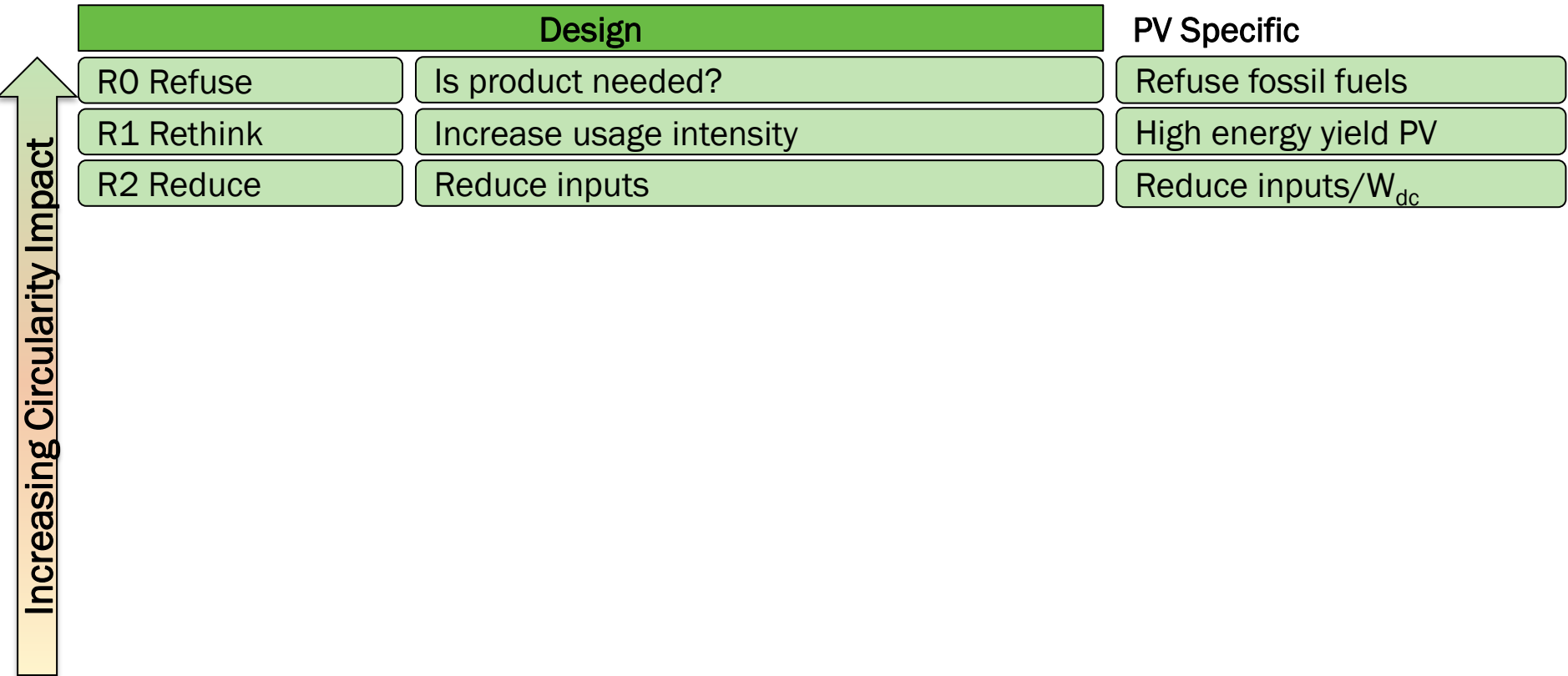


Mirletz, H., Hieslmair, H., Ovatt, S. *et al. Nat. Phys.* **19**, 1376–1378 (2023).

Old Strategies for Circularity



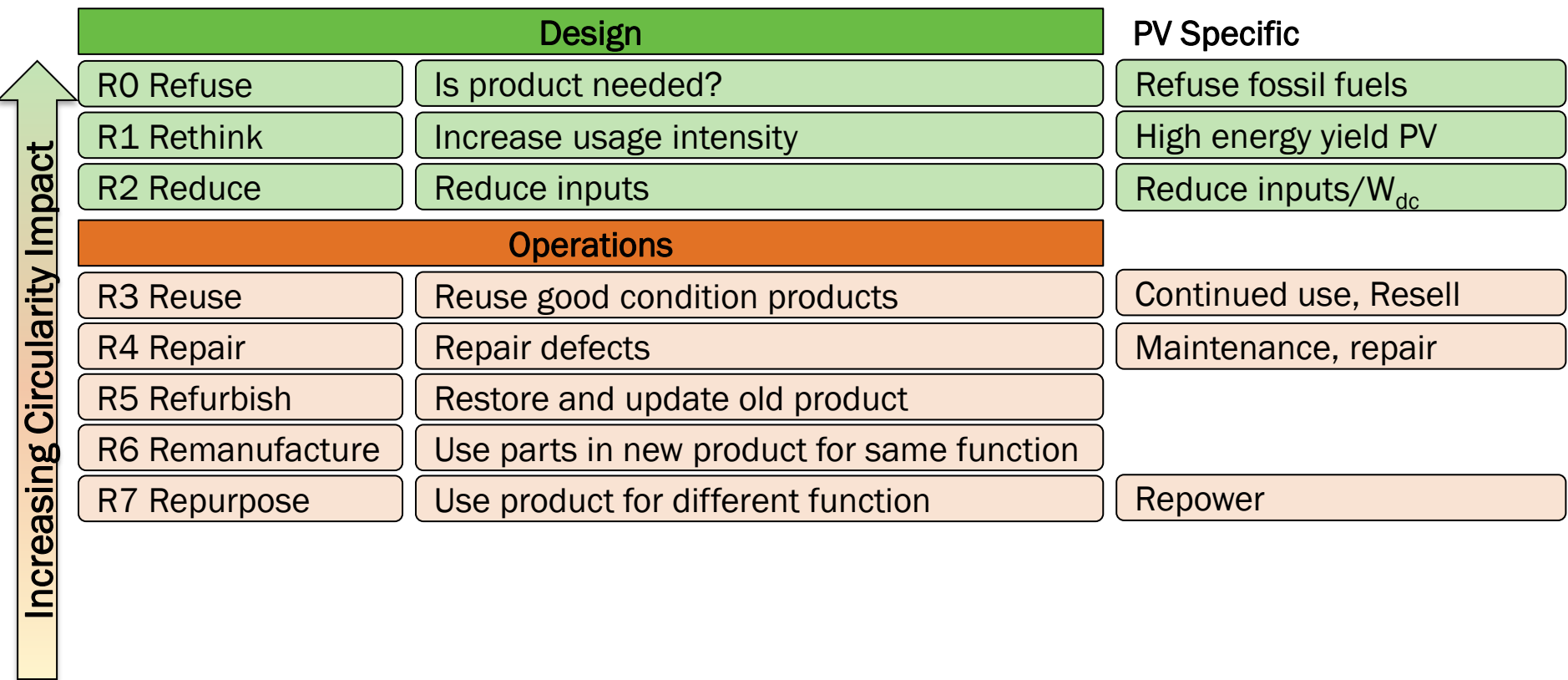
Standard Re-X Strategies for Circularity



J. Potting, M. Hekkert, E. Worrell, and A. Hanemaaijer, Circular economy: measuring innovation in the product chain. The Hague: PBL Publishers; 2017.

H. Mirlletz et al., Energy in the Balance: PV Reliability to Power the Energy Transition. PV Reliability Workshop; 2023.

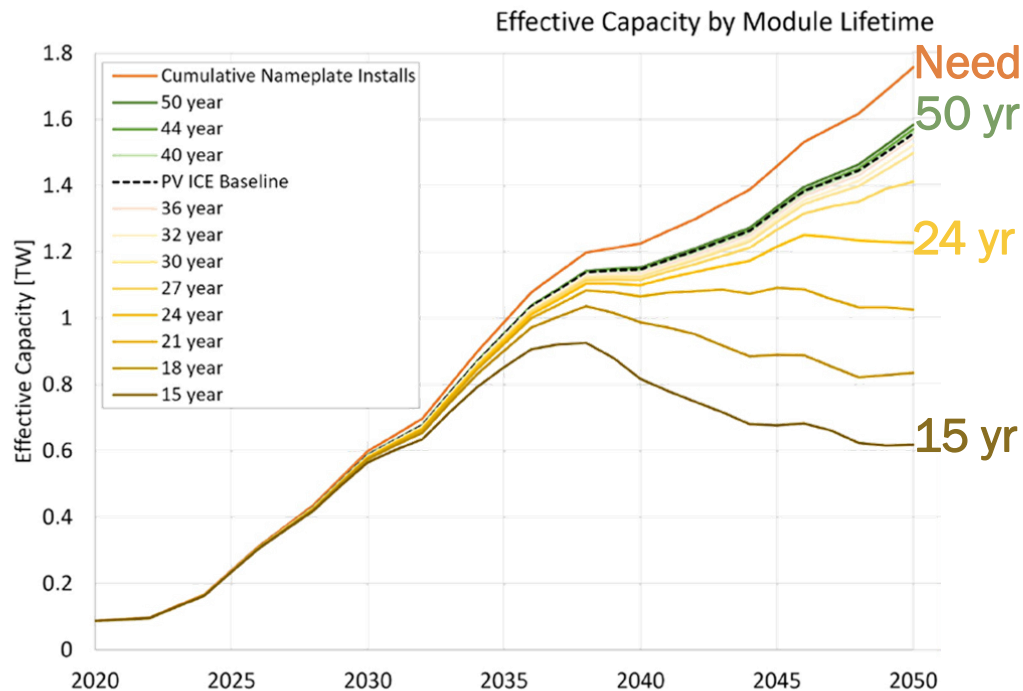
Standard Re-X Strategies for Circularity



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Operations: Maintaining and Extending Useful Life



Strategies

- Reuse
- Repair
- Refurbish
- Repurpose

Challenges

- Reducing degradation & failure
- Operation & maintenance costs and practicality
- Safety and standards
- Accurate performance tests

Need: Extend module lifetime to grow & maintain effective capacity

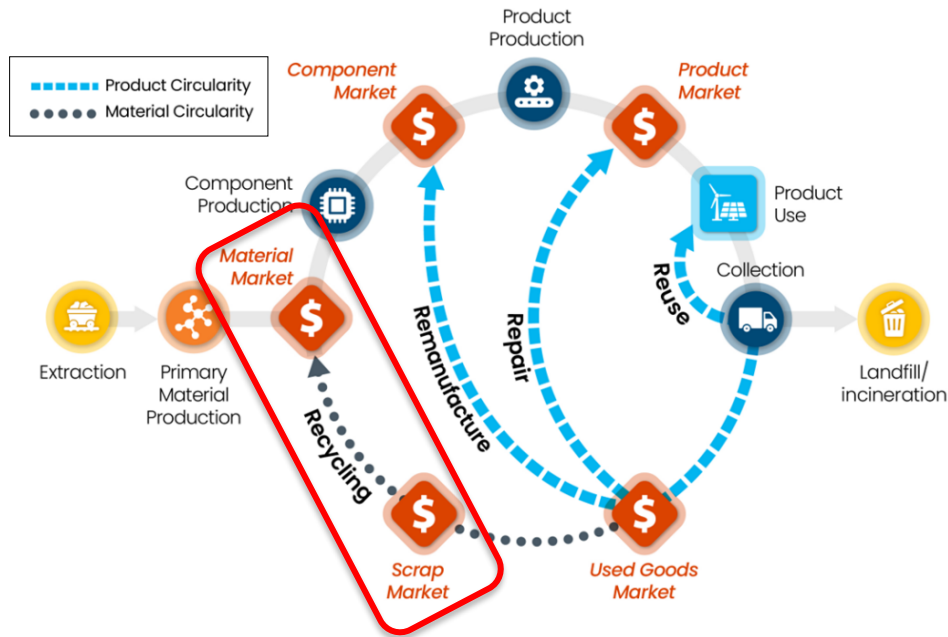
Standard Re-X Strategies for Circularity

Increasing Circularity Impact	Design		PV Specific	
	R0 Refuse	Is product needed?		Refuse fossil fuels
	R1 Rethink	Increase usage intensity		High energy yield PV
	R2 Reduce	Reduce inputs	Reduce inputs/ W_{dc}	
	Operations			
	R3 Reuse	Reuse good condition products	Continued use, Resell	
	R4 Repair	Repair defects	Maintenance, repair	
	R5 Refurbish	Restore and update old product		
	R6 Remanufacture	Use parts in new product for same function		
	R7 Repurpose	Use product for different function	Repower	
	End-of-Life			
	R8 Recycle	Process to extract materials		
R9 Recover	Energy recovery			

J. Potting, M. Hekkert, E. Worrell, and A. Hanemaaijer, Circular economy: measuring innovation in the product chain. The Hague: PBL Publishers; 2017.

H. Mirlletz et al., Energy in the Balance: PV Reliability to Power the Energy Transition. PV Reliability Workshop; 2023.

End-of-Life: Recovering Materials & Secondary Markets



Strategies

- Recycle
- Recover

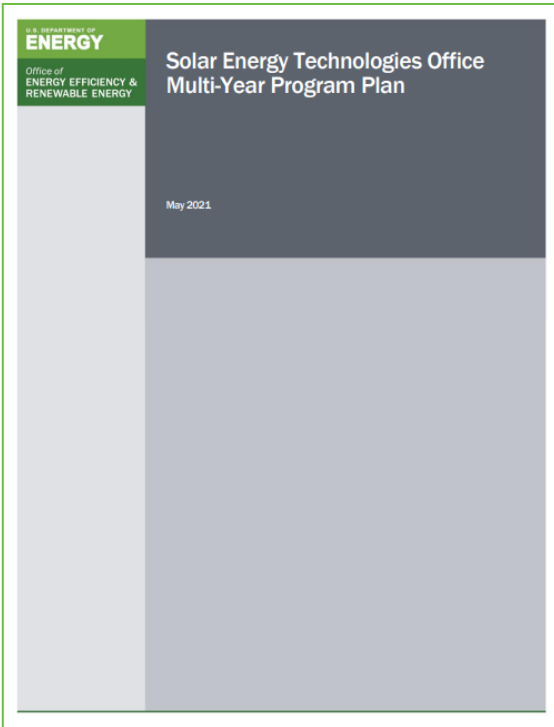
Challenges

- Recovering high purity materials
- Establishing secondary markets
 - In and out of PV
- Economics and scaling

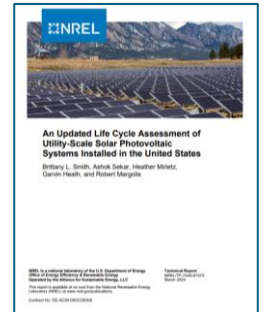
Need: Technology solutions to lower recycling costs and materials markets for next use

“Circularity for Secure and Sustainable Products and Materials: A Draft Strategic Framework” October 2024:
<https://www.energy.gov/sites/default/files/2024-10/circularity-for-secure-sustainable-products-materials-report.pdf>

SETO Multi-Year Program Plan 2021 – PV Goals



- Lowering the cost of energy from PV
- Reducing the life cycle impacts of solar energy
 - New materials, designs, and practices for reducing the environmental impact of PV technology
 - Life cycle impacts benchmark



<https://www.energy.gov/eere/solar/articles/solar-energy-technologies-office-multi-year-program-plan>

<https://www.nrel.gov/docs/fy24osti/87372.pdf>

SETO Funding Programs Overview



SETO has numerous, diverse programs and prizes working on improving the positive environmental impact of solar

Research Projects: <https://www.energy.gov/eere/solar/solar-energy-research-database>
 Prizes: <https://www.energy.gov/eere/solar/american-made-challenges>
 2024 Peer Review: <https://www.energy.gov/eere/solar/2024-seto-peer-review>

- Collaborations
- Lifecycle Tracking
- Lower Carbon Silicon Ingots
- Precious Metal Minimization
- Encapsulant Challenges
- Reuse and Repowering
- Precious Metal Recovery
- Recycling





QUESTIONS

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