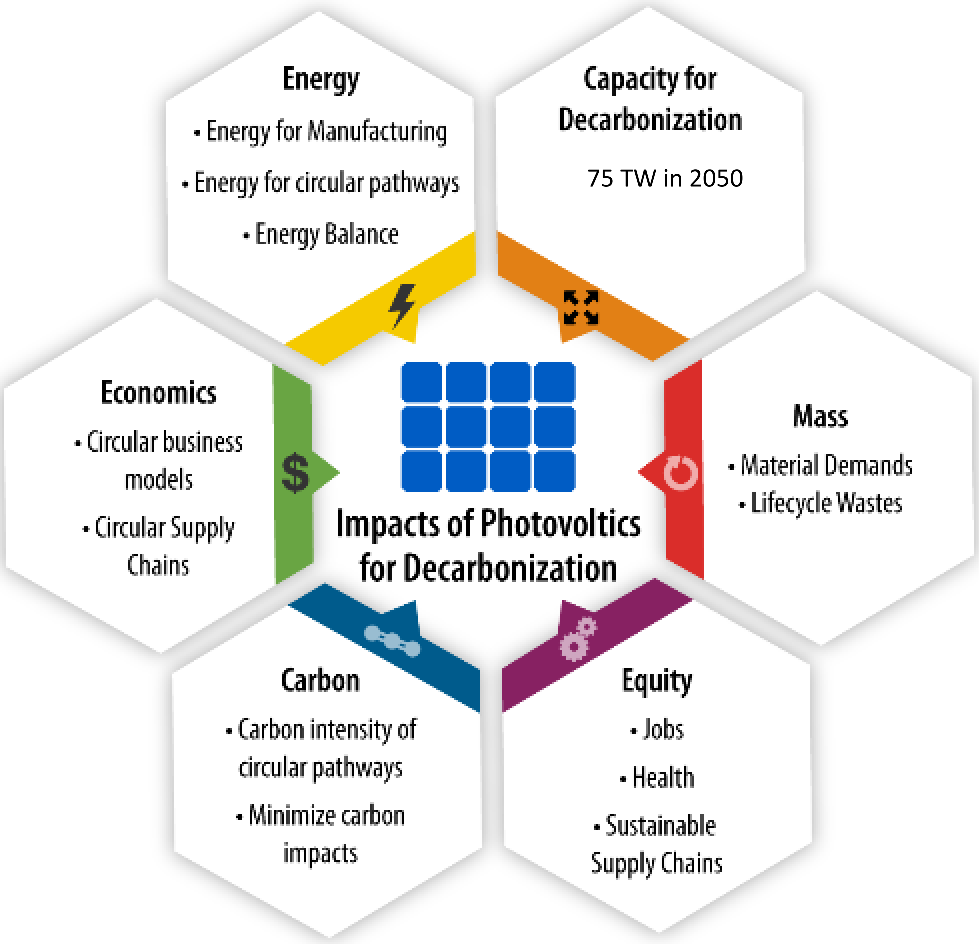


Removing barriers to 100% Renewables

Silvana Ovaitt, Heather Mirletz, Teresa M. Barnes

100% Renewables Panel - Parallel Event

EUPVSEC September 19th, 2023

Tsunami of waste?

The Washington Post
Democracy Dies in Darkness

Scientists found a solution to recycle solar panels in your kitchen

Research suggests microwave technology could make it easier to tak

By Allyson Chiu

July 5, 2023 at 6:30 a.m. EDT

Sustainable Business Practices

The Dark Side of Solar Power

As interest in clean energy surges, used solar panels are going straight into landfill. by Atalay Atasu, Serasu Duran, and Luk N. Van Wassenhove

June 18, 2021

MADDIE STONE SCIENCE AUG 22, 2020 8:00 AM

Solar Panels Are Starting to Die, Leaving Behind Toxic Trash

Photovoltaic panels are a boon for clean energy but are tricky to recycle. As the oldest ones expire, get ready for a solar e-waste glut.

Circular Economy is not enough

Virgin Material

Waste

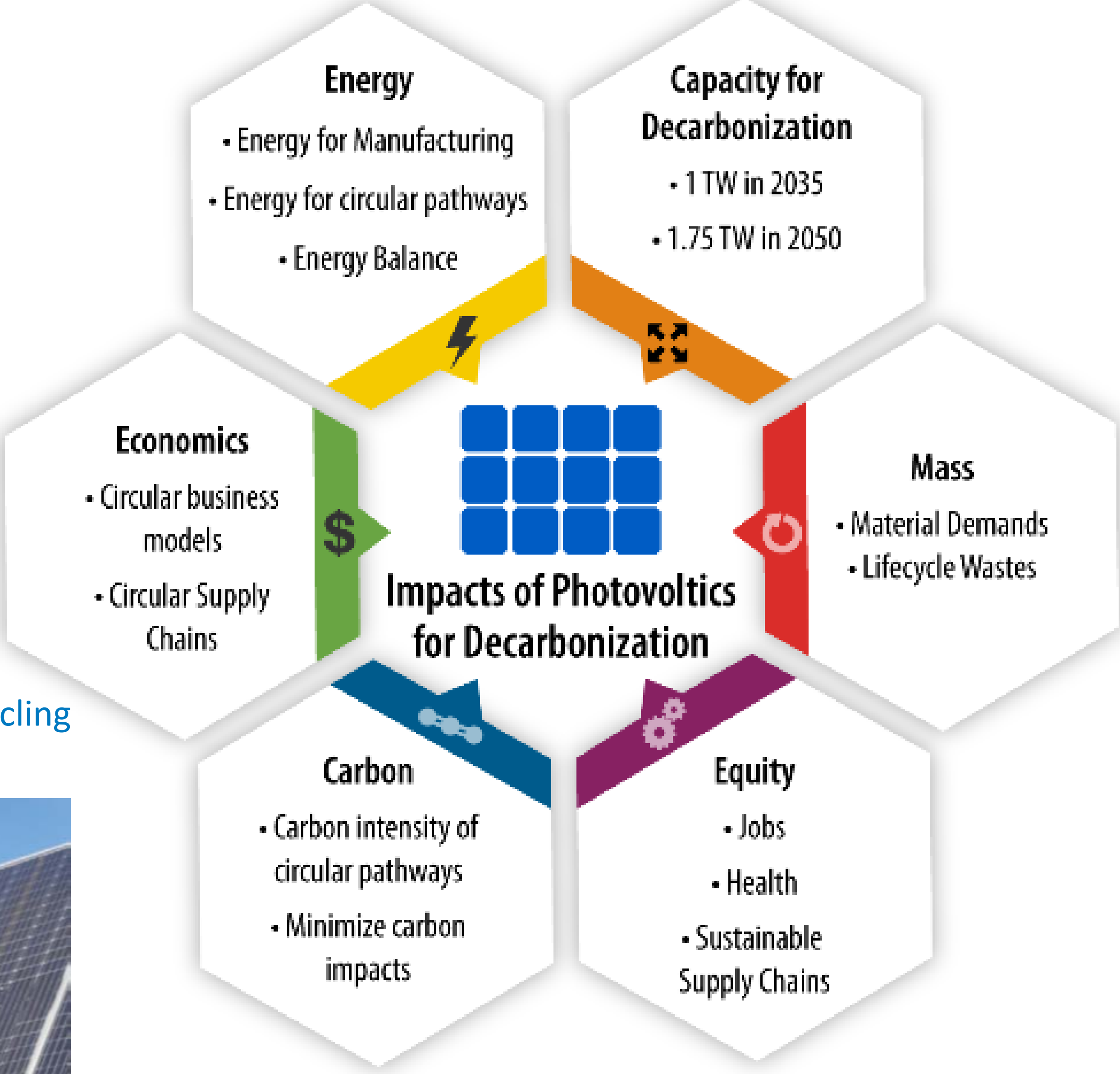
$$CI = 1 - \frac{V + W}{2M + \sum_x \frac{W_{F(x)} - W_{R(x)}}{2}}$$

Mass of the product

Waste from Feedstock & Manufacturing

Waste from recycling process

≠



PV is closer to construction building waste than to e-waste

- Lifetime
- Solder content
- Plastic content
- Glass content

32 Years
-0.7% Degradation Rate

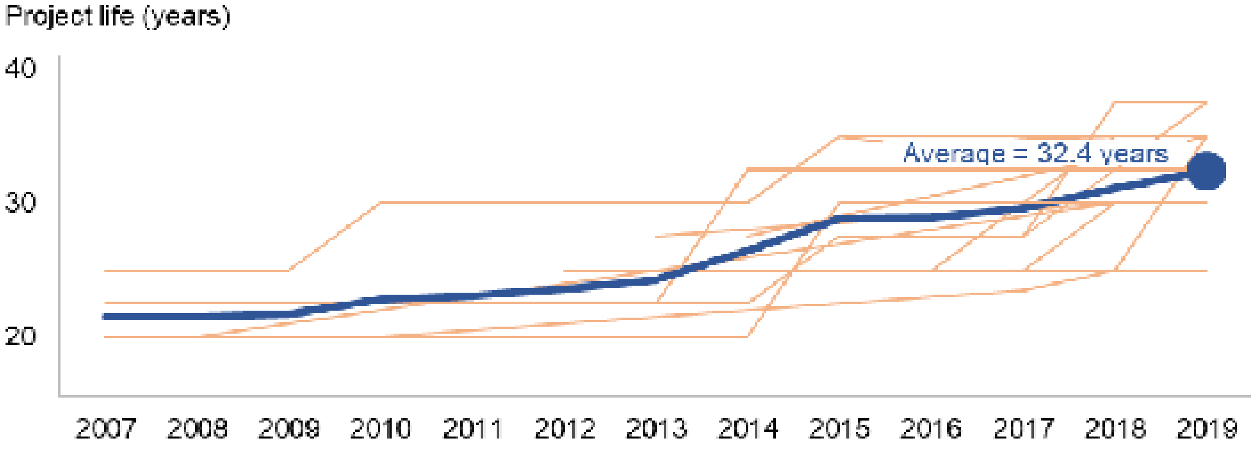
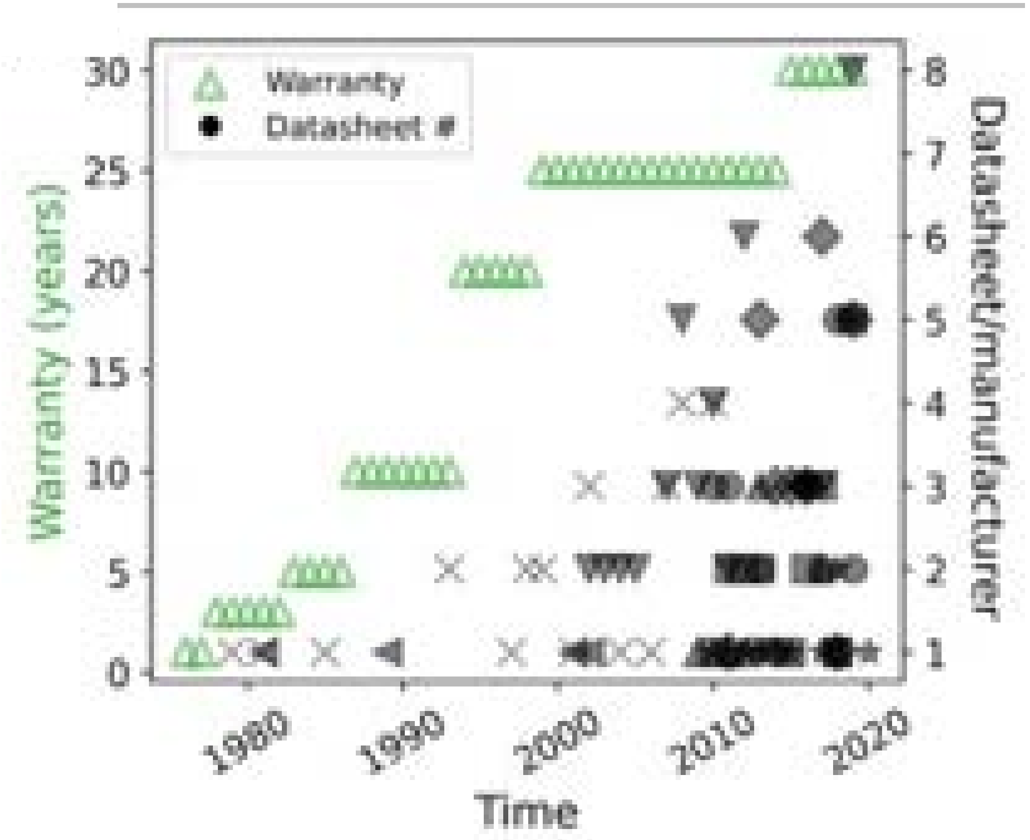


Figure 2. Project Life Expectations for Utility-Scale PV, over Time



[1]D. Jordan, Photovoltaic Module Reliability for the TW Age, Progress in Energy 2022, 10.1088/2516-1083/ac6111
[2] Wiser, LBL, 2020

PV toxicity

U.S. state health department websites:

- Arsenic
- Gallium

} III-Vs for aerospace

- Germanium → Once used in amorphous silicon not at scale
- Hexavalent Chromium → Not used in cells Water heaters?

Others

- Cadmium (CdTe) – Closed-loop recycling success story
- PFAs – **multiple** fluorine atoms

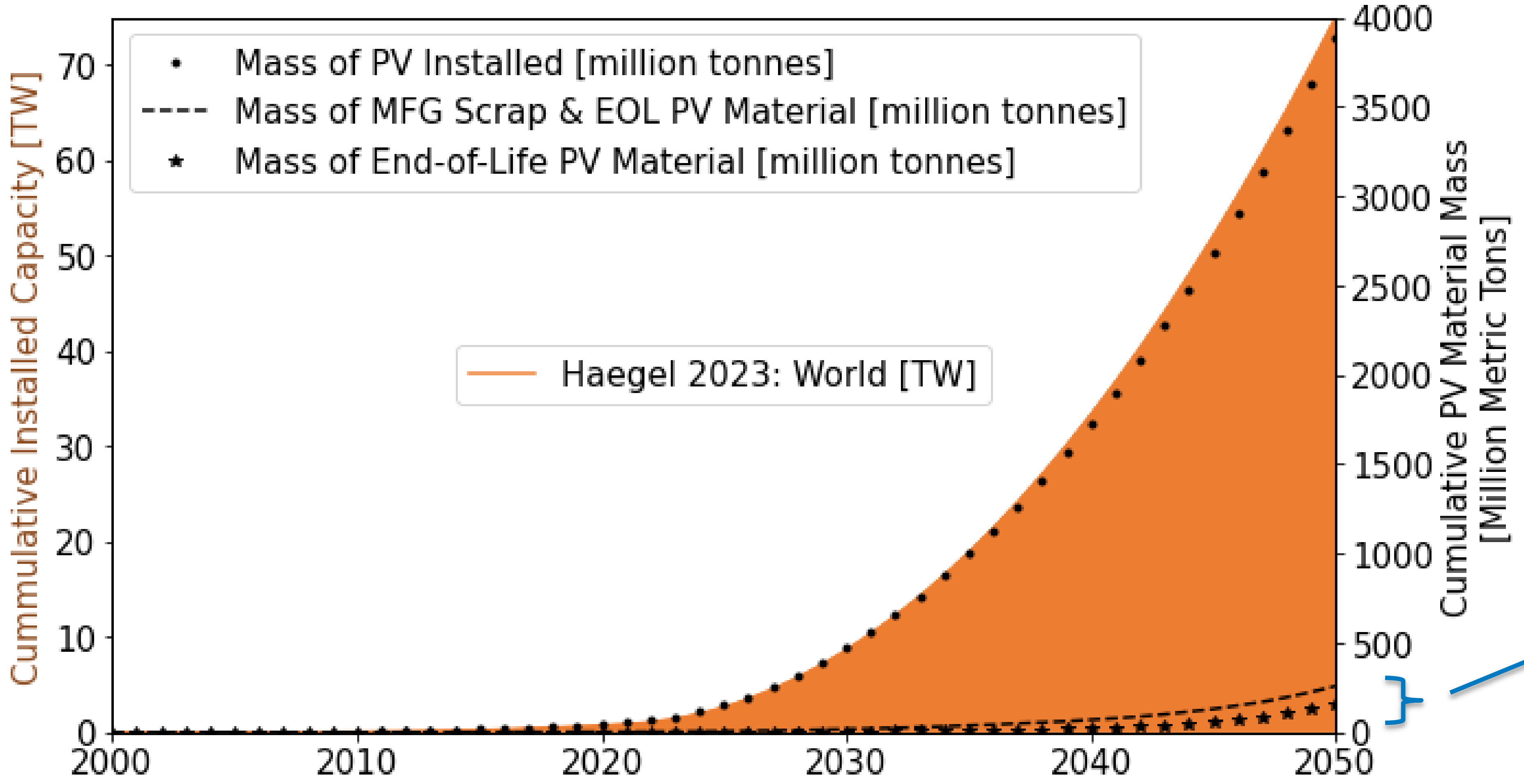
Self cleaning coats? Many non-hazardous silicon chemistry; commercial self-cleaning options (non-solar) contain some.
Adhesives? Solar adhesives based on silicon polymers
Backsheets? Tedlar - weather resistant polymer that is not a PFAS compound itself and makes no use of PFAS during its manufacturing process. Some other have fluorinated compounds, but they are not free PFAs as long as you don't burn.

A. Anctil (2023) "Facts about solar panels: PFAS contamination."

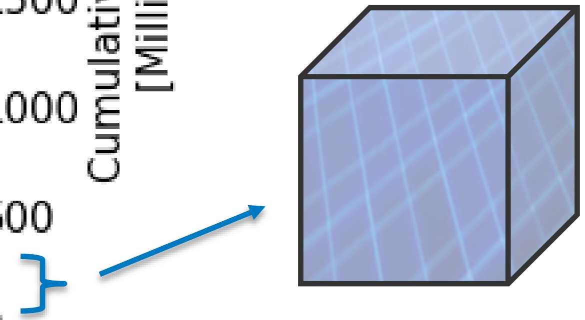
Mirletz, Hieslmair, Ovaitt, Curtis, Barnes. **Unfounded concerns about photovoltaic module toxicity and waste are slowing decarbonization**. NATURE, 2023 [10.1038/s41567-023-02230-0](https://doi.org/10.1038/s41567-023-02230-0)
Full access: https://rdcu.be/dnOZR

Waste

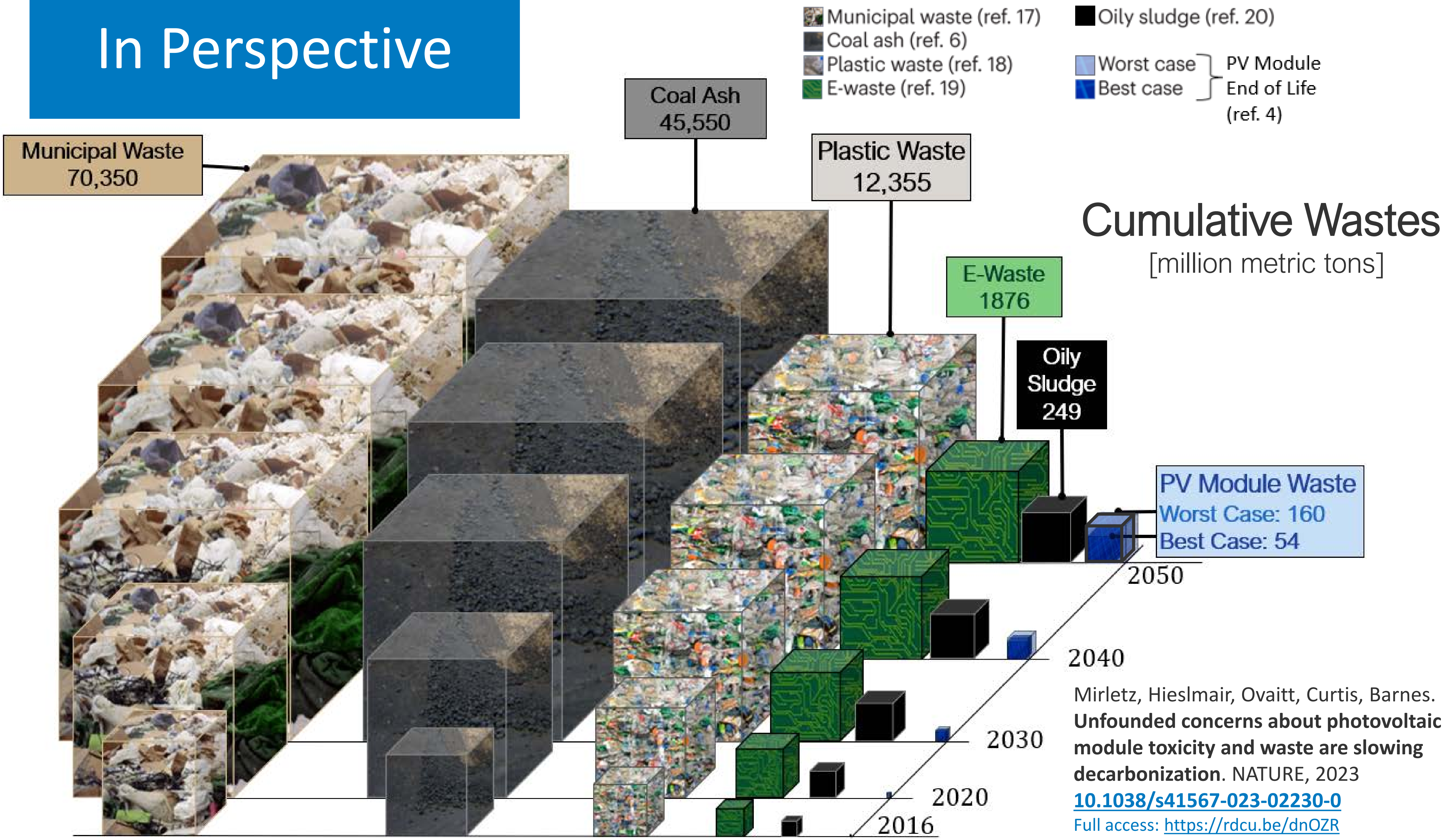
Waste



Mass of PV Installed [million tonnes]
Mass of MFG Scrap & EOL PV Material [million tonnes]
Mass of End-of-Life PV Material [million tonnes]
Haegel 2023: World [TW]
Cummulative Installed Capacity [TW]
Cumulative PV Material Mass [Million Metric Tons]
0
10
20
30
40
50
60
70
2000
2010
2020
2030
2040
2050
0
500
1000
1500
2000
2500
3000
3500
4000



In Perspective



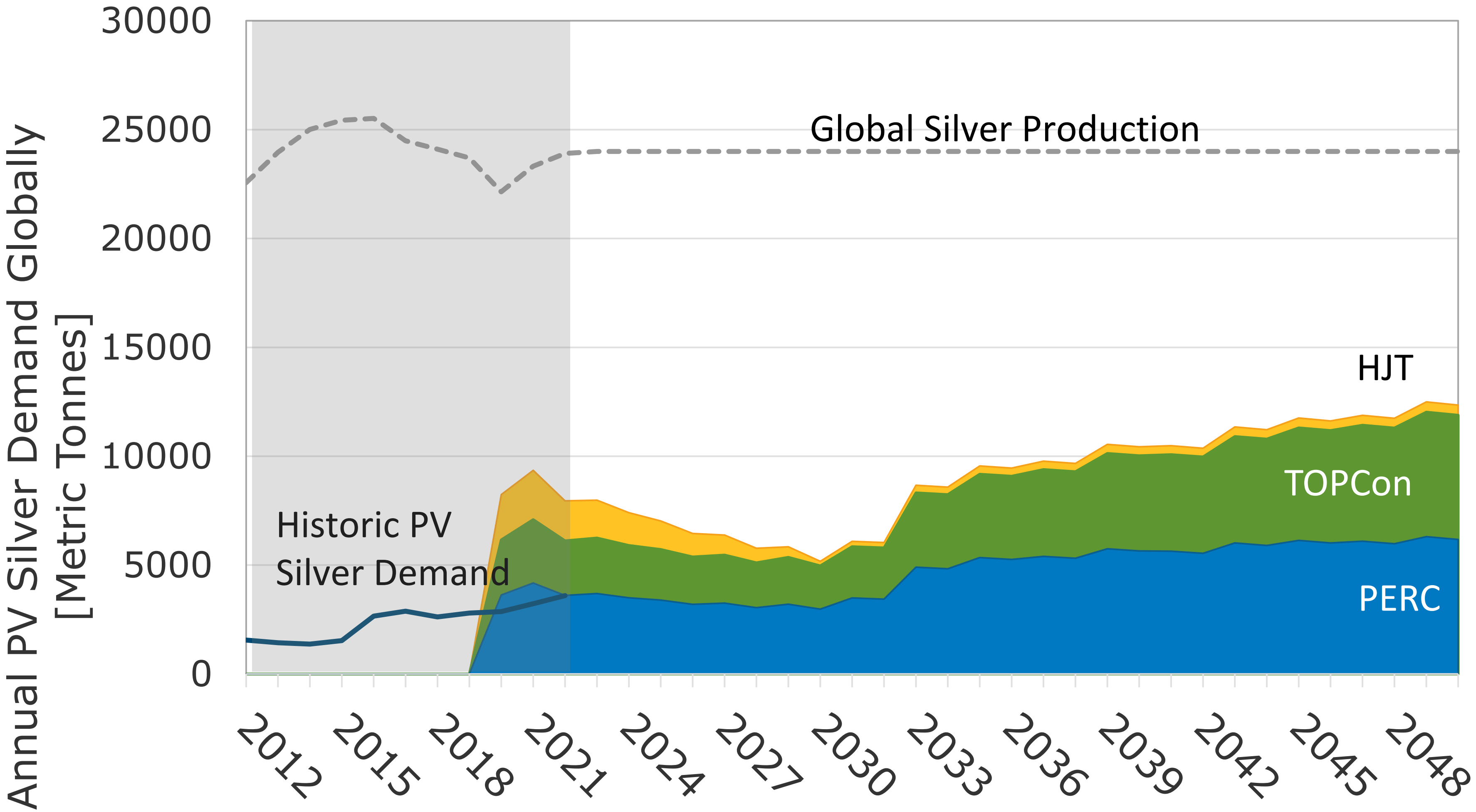
Mirletz, Hieslmair, Ovaitt, Curtis, Barnes. **Unfounded concerns about photovoltaic module toxicity and waste are slowing decarbonization.** NATURE, 2023
[10.1038/s41567-023-02230-0](https://doi.org/10.1038/s41567-023-02230-0)
Full access: https://rdcu.be/dnOZR

Is there enough virgin material?

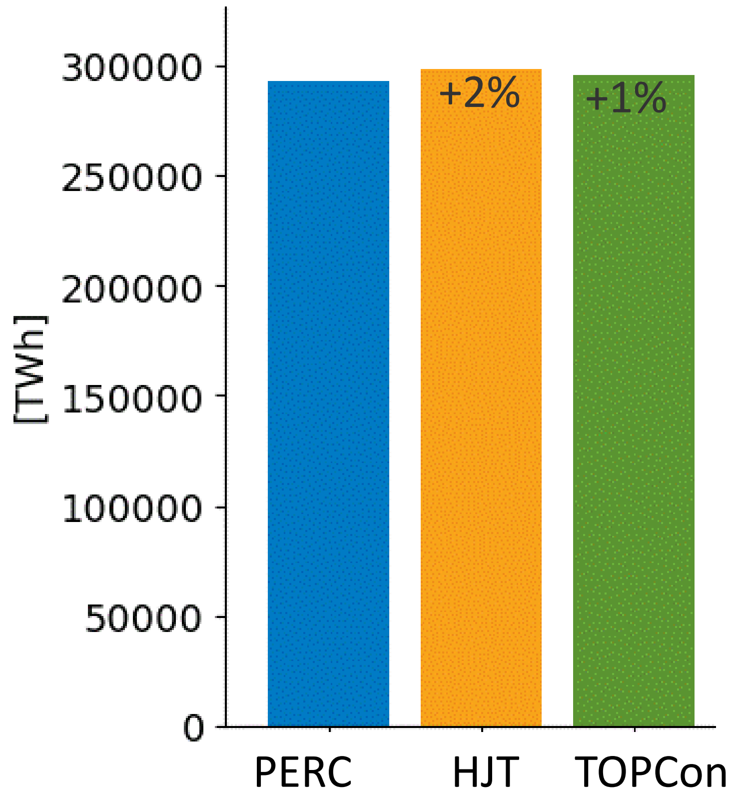
Virgin Material

Energy In

Energy Out



Cumulative Energy Generated



Barnes, et al. 5th International SHJ Workshop, CEA-INES 2022

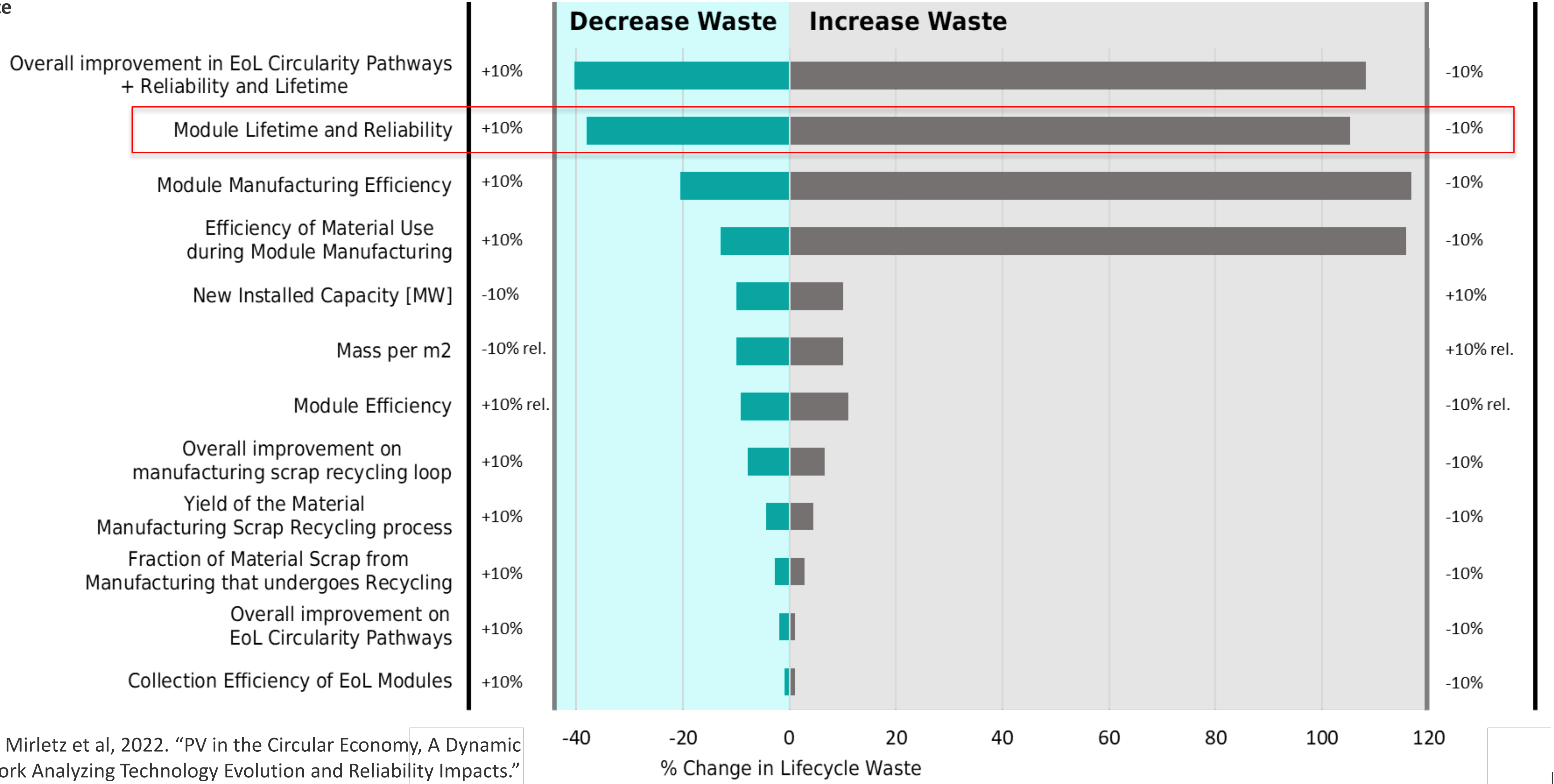
There’s a priority for R’s, and Recycling is not at the top

	R-Strategies	Generalized Description	Proposed PV Specific
Decarbonization First	**R0: Refuse**	Refuse fossil fuels and carbon intensive materials	**Decarbonize First** **Refuse Virgin and Conflict Materials**
	R1: Rethink	System design and integration for net energy yield over time	High energy yield PV systems Future proofing/backward compatible Design for Repair and Reliability Integrated PV
	R2: Reduce	Reduce energy, material, and carbon input	**Reduce Material usage/W_p** Material substitution Increase manufacturing yield Decarbonize manufacturing
Maximize Net Energy	R3: Reuse	Re-use if good condition	Merchant Tail, Resell in secondary market
	R4: Repair	Repair and maintenance for extended life	Onsite repair of modules and components
	R5: Refurbish	Restore older to updated functionality	Demount and transport modules for repairs Replace storm damaged modules on site
	R6: Remanufacture	Use parts in new product for same function	Disassemble, replace cells, relaminate
	R7: Repurpose	Use parts in new product with different function	Repower system with new components
Turn waste into feedstock	R8: Recycle	Process materials, high or low quality	Separate modules and components, reclaim materials
	R9: Remine	Landfill mining	Mine input materials from landfills, refine
	R10: Recover	Energy recovery through incineration	Burn component materials for energy generation

Mirletz, Ovaitt, Barnes, 2022 "Quantifying Energy flows in PV Circular Processes"
PVSC Proceedings. Best Student Paper Area 8 Award

And the most important R is not even in that list

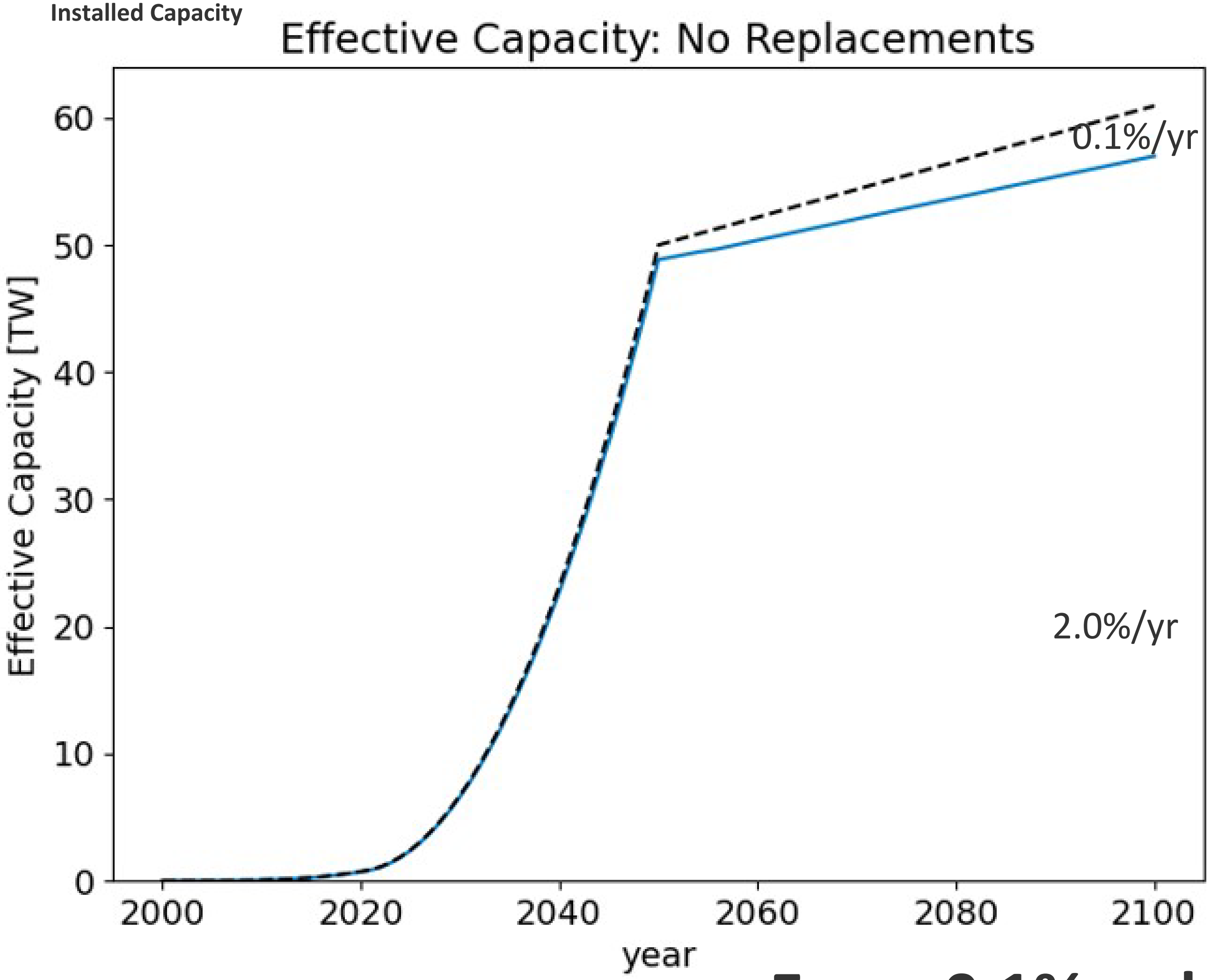
Waste

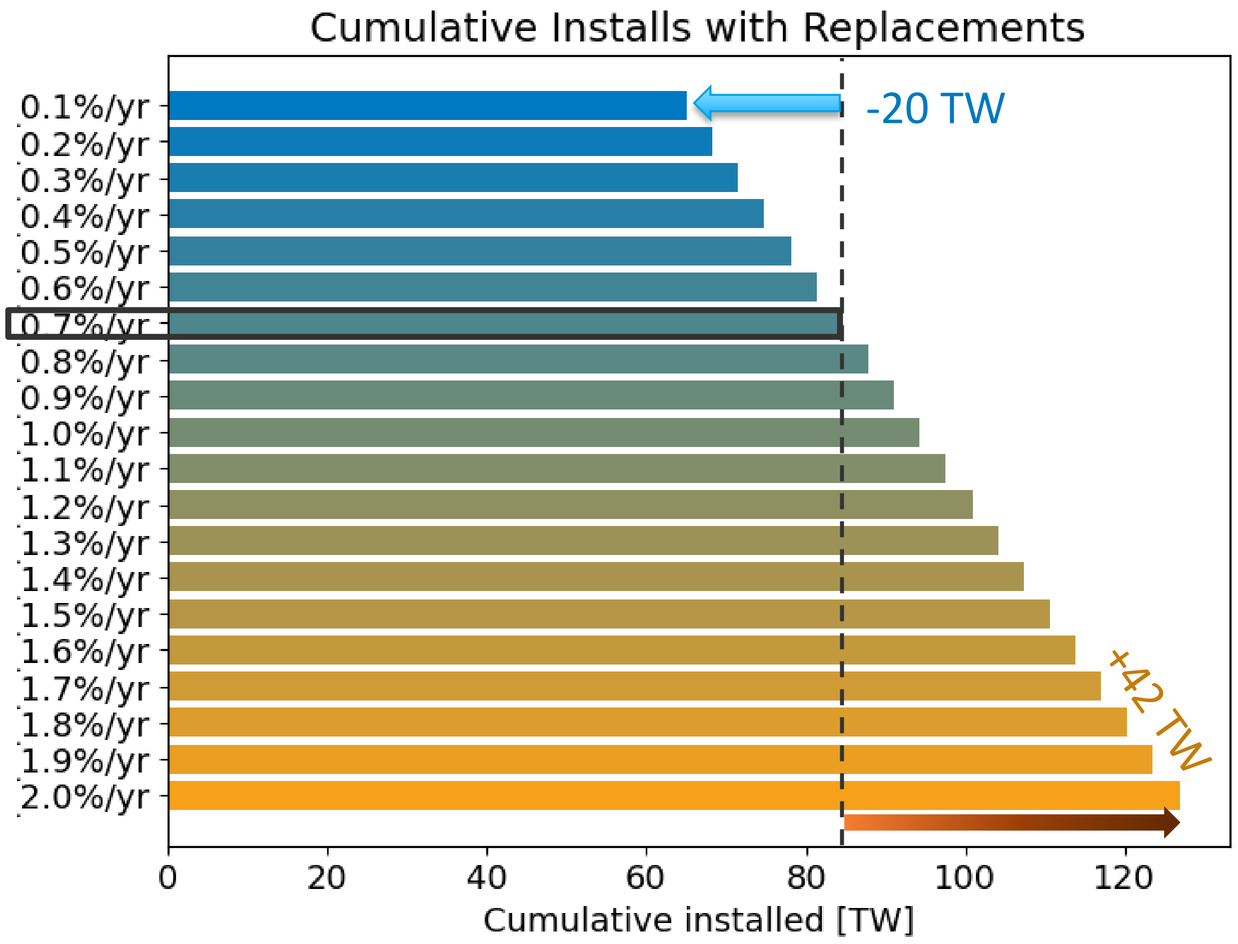


Ovaitt & Mirletz et al, 2022. “PV in the Circular Economy, A Dynamic Framework Analyzing Technology Evolution and Reliability Impacts.” *ISCIENCE* https://doi.org/10.1016/j.isci.2021.103488.

The concept of Installs vs Effective Capacity

Installed Capacity

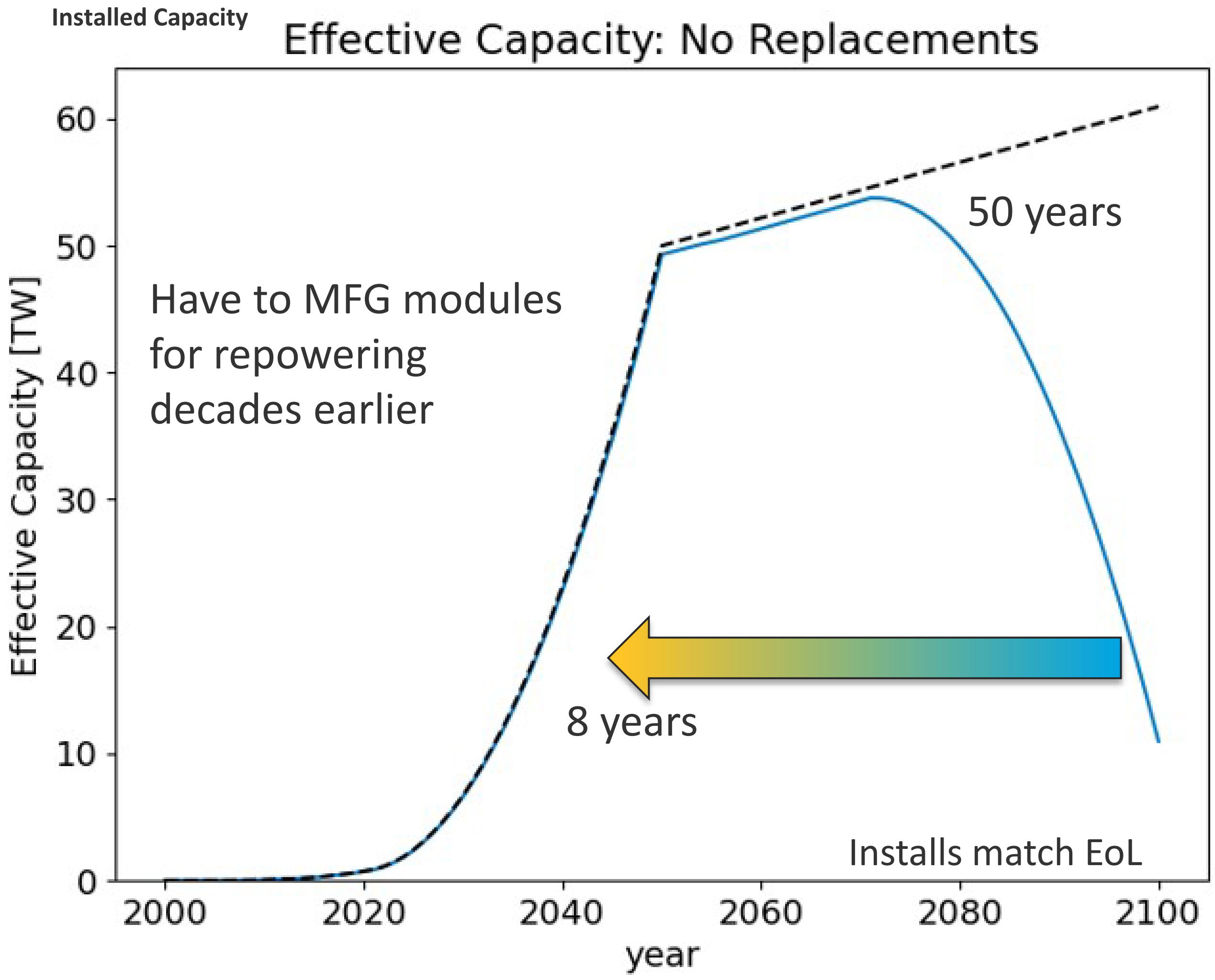


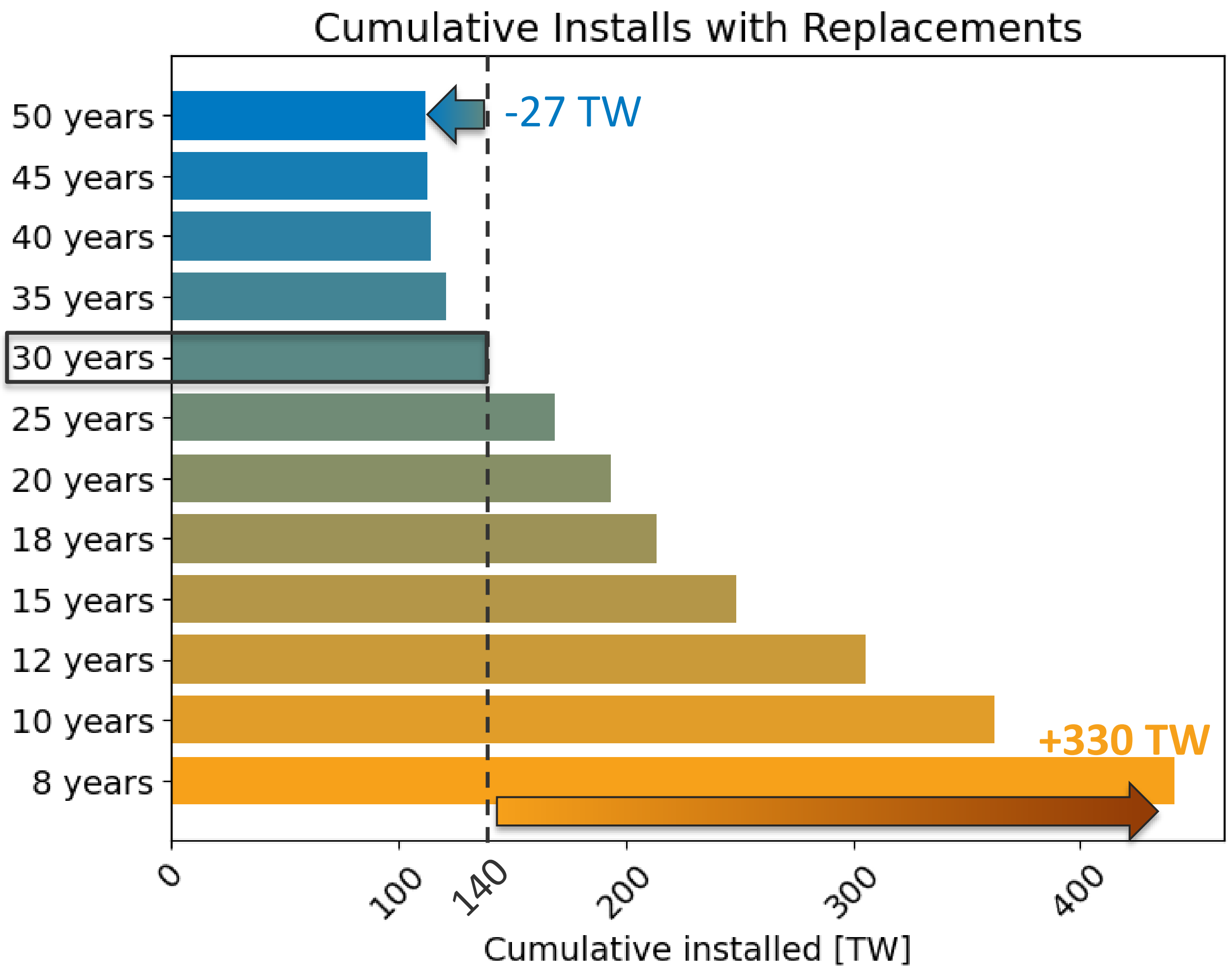


Every 0.1% reduction in degradation saves ~3 TW of replacements

Threshold: remove at 80% of nameplate

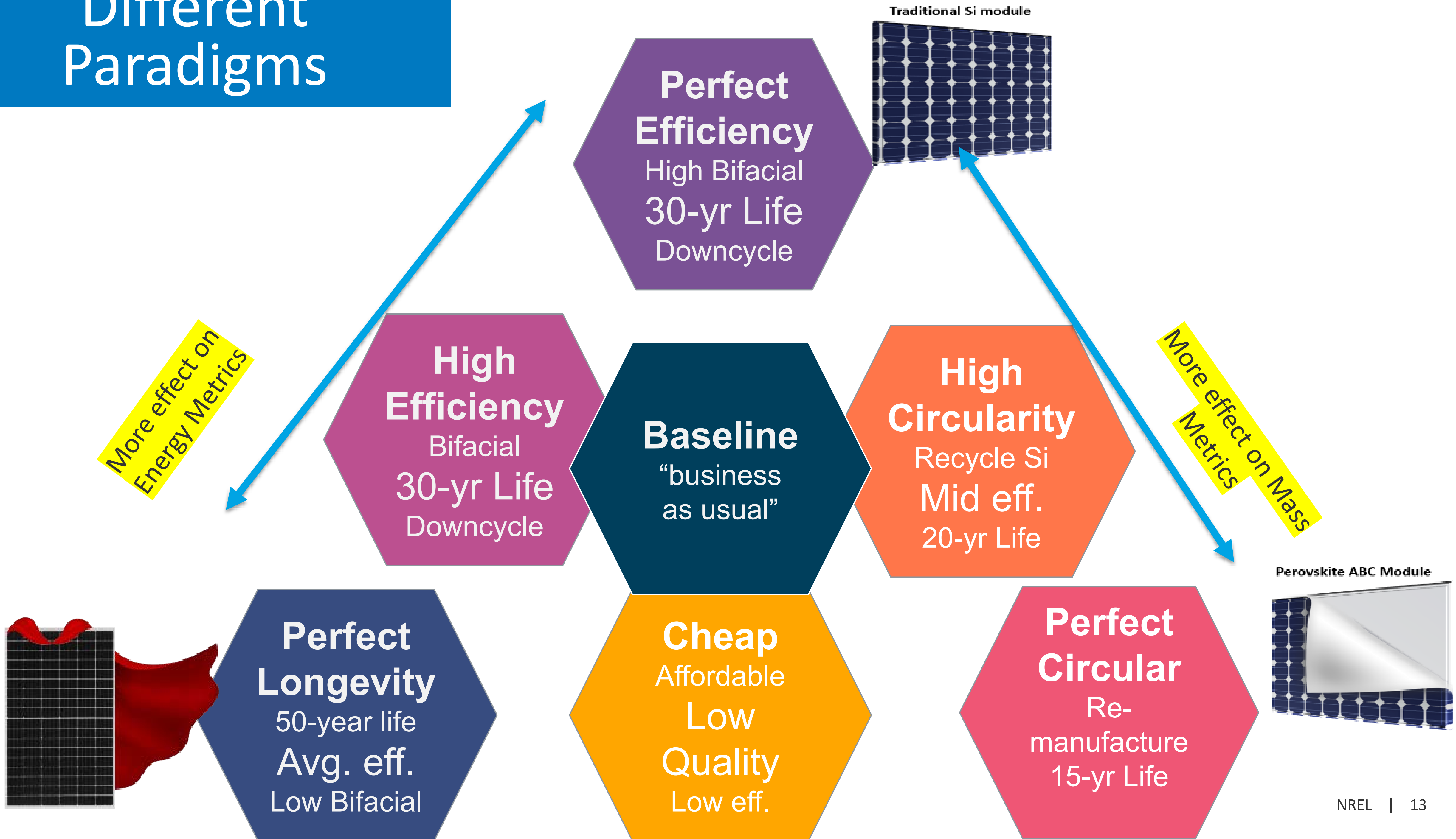
The concept of Installs vs Effective Capacity





Short project lifetimes require more replacements, sooner

Different Paradigms



Different Paradigms

Ms. Heather Mirletz

NREL - NATIONAL RENEWABLE ENERGY LABORATORY

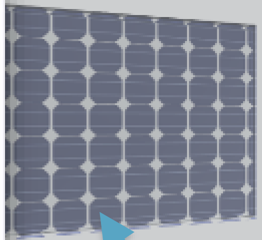
5CO.6.6

More Than Recycling: How Should We Define Circularity Goals for PV in a Global Energy Transition?

Wednesday, 20 September 2023,

Session 5CO.6, 17:00 - 18:30

Traditional Si module

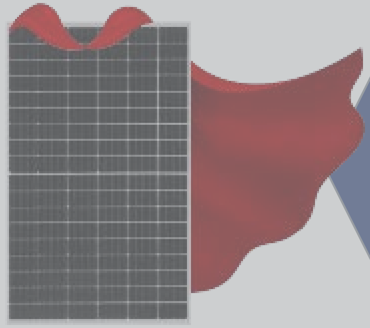


More effect on Energy Metrics

High Efficiency
Bifacial
30-yr Life
Downcycle

High Circularity
Recycle Si
Mid eff.
20-yr Life

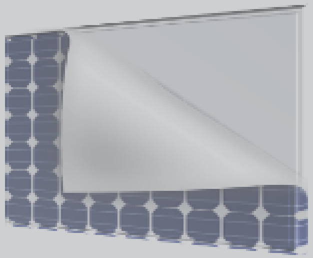
More effect on Mass Metrics



Perfect Longevity
50-year life
Avg. eff.
Low Bifacial

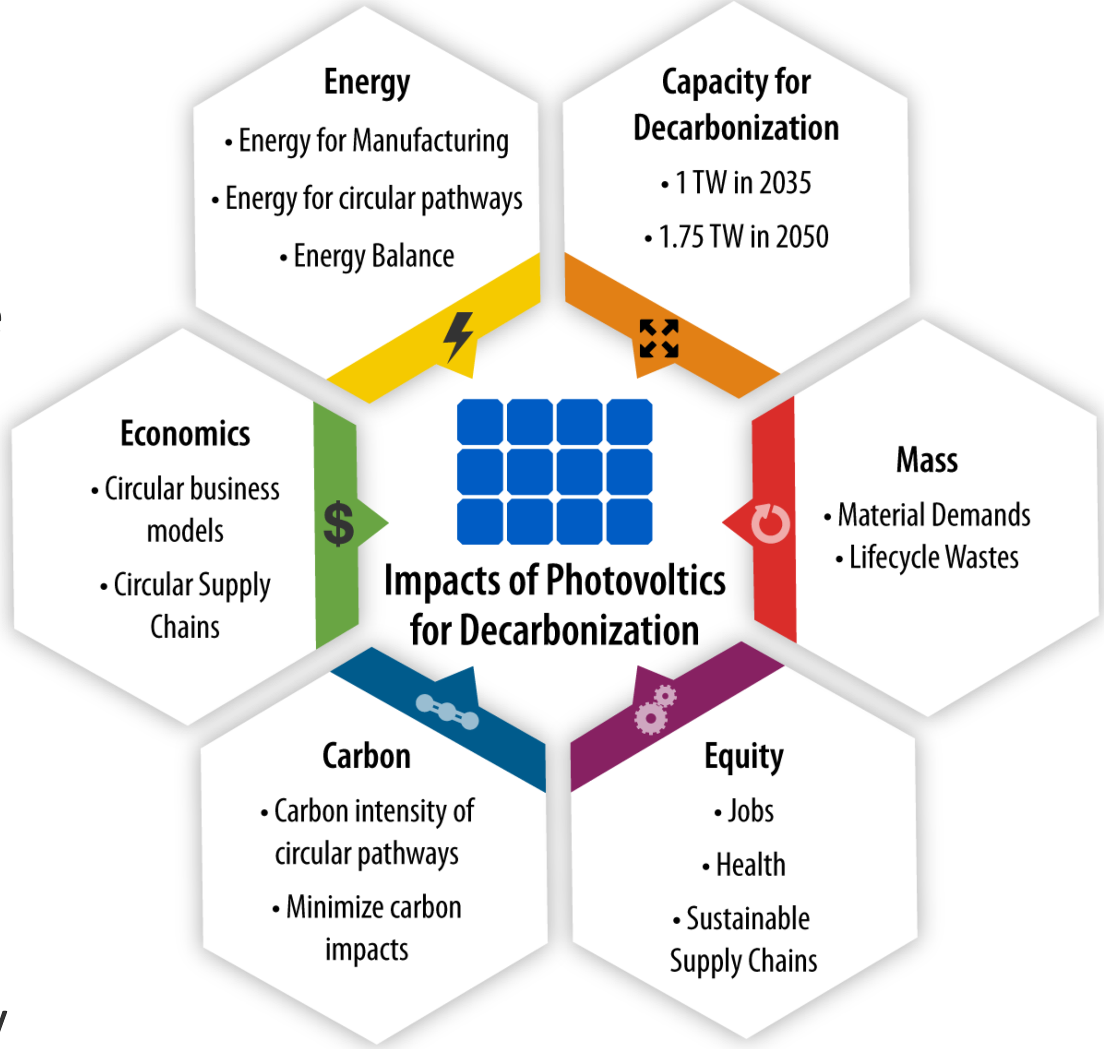
Perfect Circular
Re-manufacture
15-yr Life

Perovskite ABC Module



Conclusions

- Reliable, long-life modules AND systems are critical for meeting capacity and decarbonization targets
- Deploy reliable PV as fast as we can, learn faster, and keep getting better – unprecedented speed with little room for error
- **Need a strong scientific and technical foundation**
- Eyes on the prize – we aren't competing between PV technologies
- More sustainable manufacturing is often more efficient and reduces costs
- End-of-life waste is manageable with steady improvements in technology, policy, and economics.
  - Waste volumes will scale with recycling capacity
  - Circularity opportunities – i.e. glass



Minimize embedded carbon and energy

www.nrel.gov

silvana.ovaitt@nrel.gov

nrel.gov/pv/pv-ice-tool.html

This work was authored [in part] by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) agreements 38269 and 38699. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

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