SCHOOL OF PUBLIC POLICY
CENTER FOR GLOBAL SUSTAINABILITY

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

Maryland
Department of the Environment

Solar Photovoltaic Systems Recovery, Reuse, and Recycling

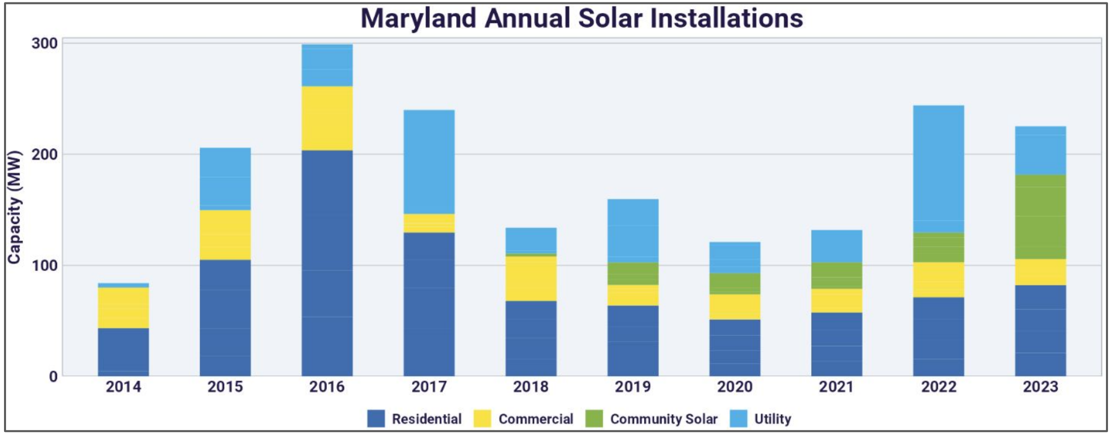
Working Group Meeting
Aug 19, 2024

Preliminary results

Agenda

- Profile of current Maryland solar installations
- End-of-life options in a PV circular economy
    - Policy examples & financing approaches
- Overview of PV-ICE model
- Modeling scenarios
- Landfills and Solar
- Next Steps

More solar deployment needed to reach Maryland’s goals



- Current capacity: 2,183 MW
- Expected growth next 5 years (SEIA): 2,314 MW
- Estimated additional capacity needed by 2030 to reach 14.5% RPS goal: 3,994 MW

Maryland Solar (>1MW)	Share of total	Nameplate Capacity (MW)
c-Si	91.80%	478.4
CdTe	7.80%	40.7
a-Si	0.40%	2.1
All sites	100.00%	521.2

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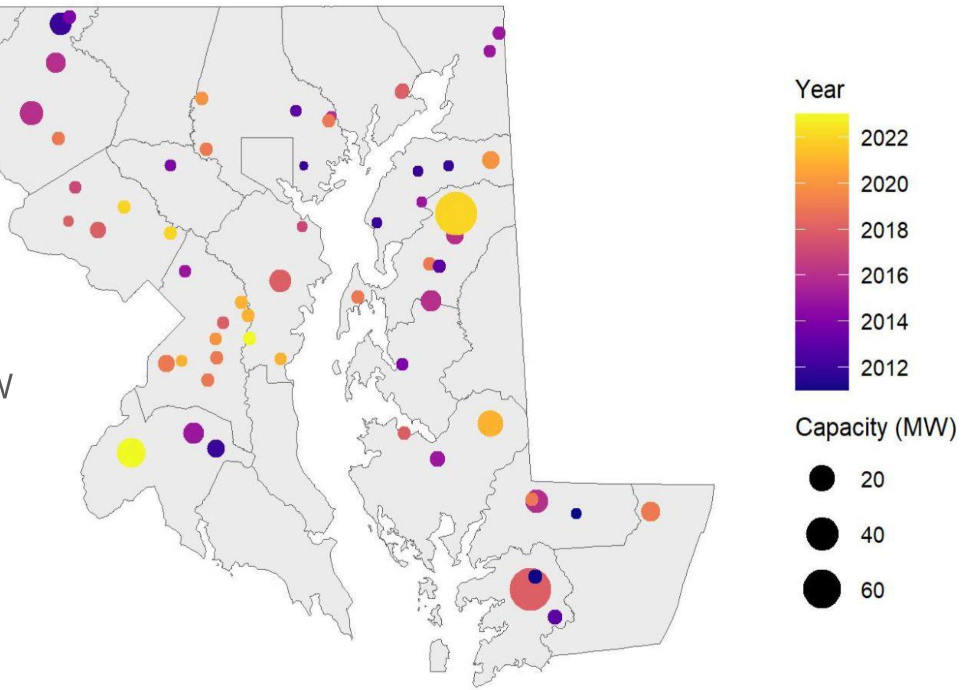
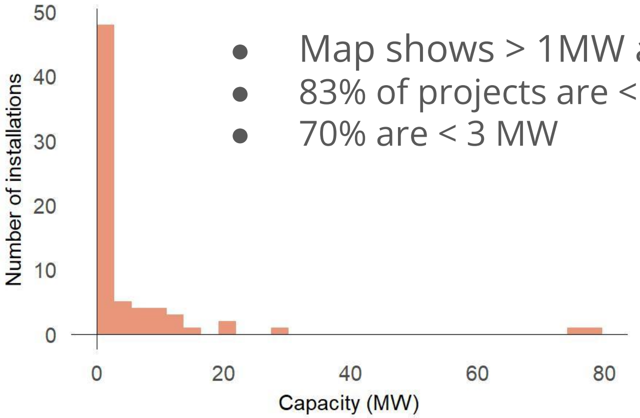
Sources: EIA860, EIA861, SEIA, Maryland Climate Pollution Reduction Plan Data

Largest utility-scale solar arrays are on Eastern Shore, with very few facilities in Western Maryland





- Map shows > 1MW arrays
- 83% of projects are < 11 MW
- 70% are < 3 MW

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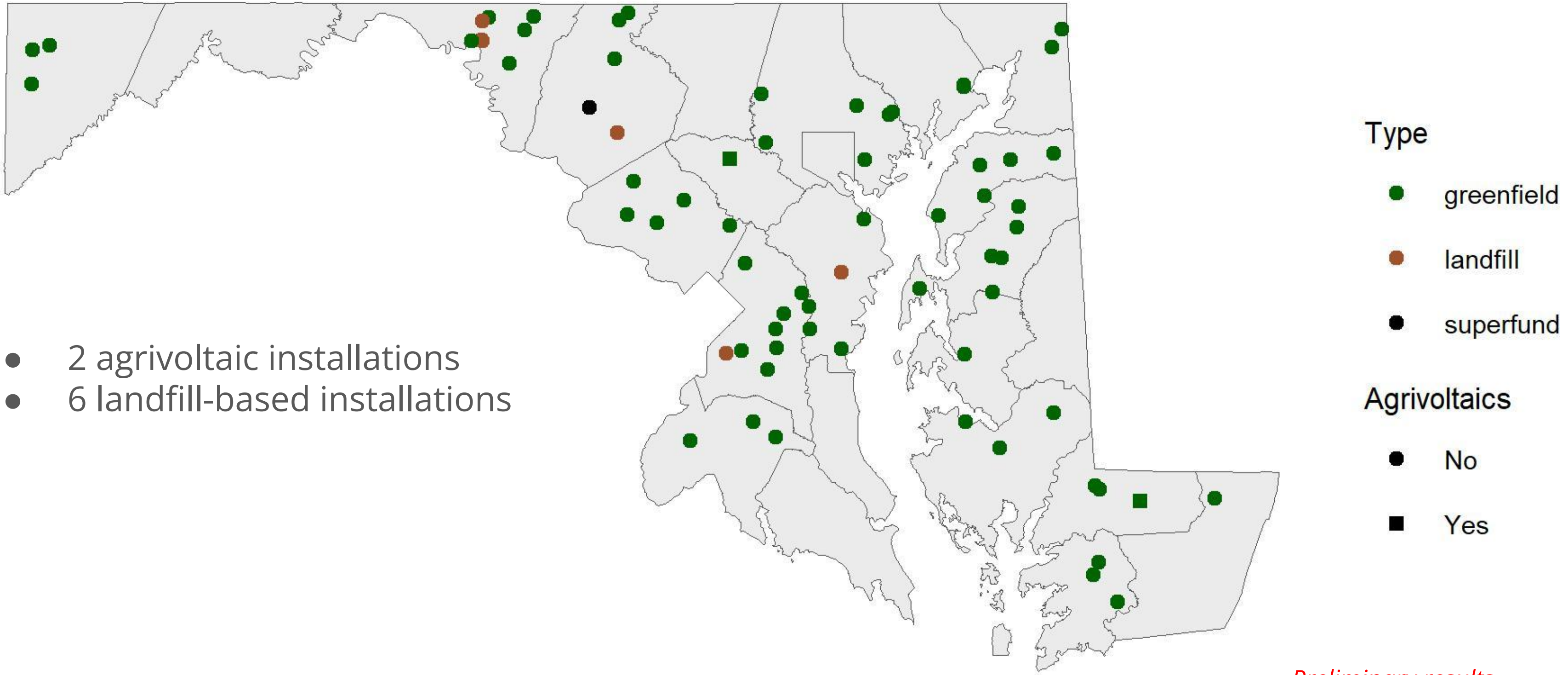
Source: LBNL, USGIS, EIA Form 860

Utility-scale solar installations are dominated by greenfield development

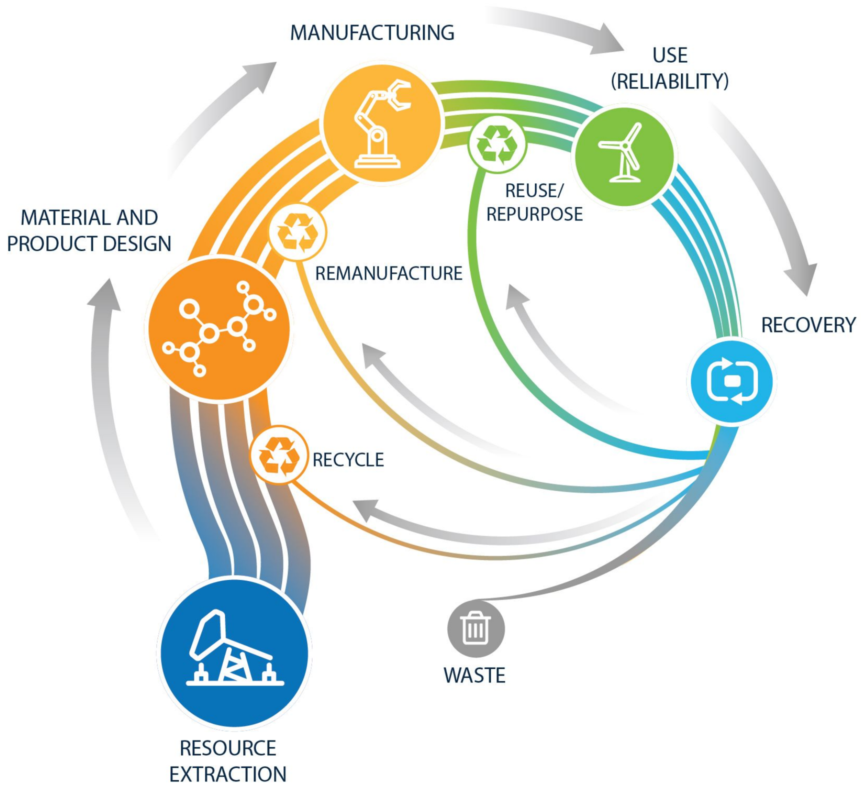


- 2 agrivoltaic installations
- 6 landfill-based installations

Preliminary results

Source: LBNL, USGIS, EIA Form 860

Circular Economy (CE) for Solar PV Systems



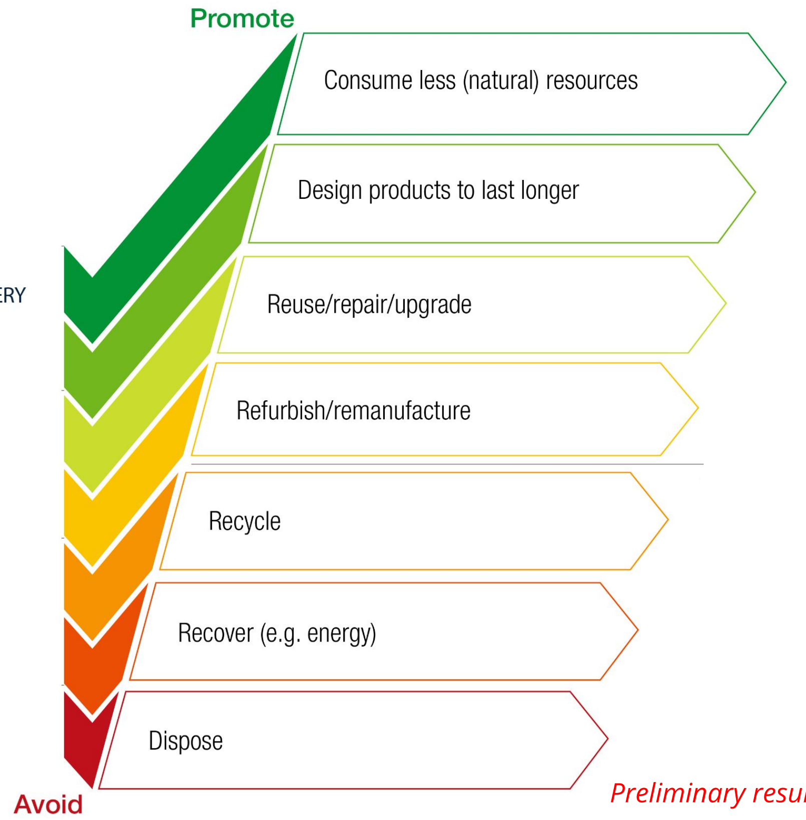


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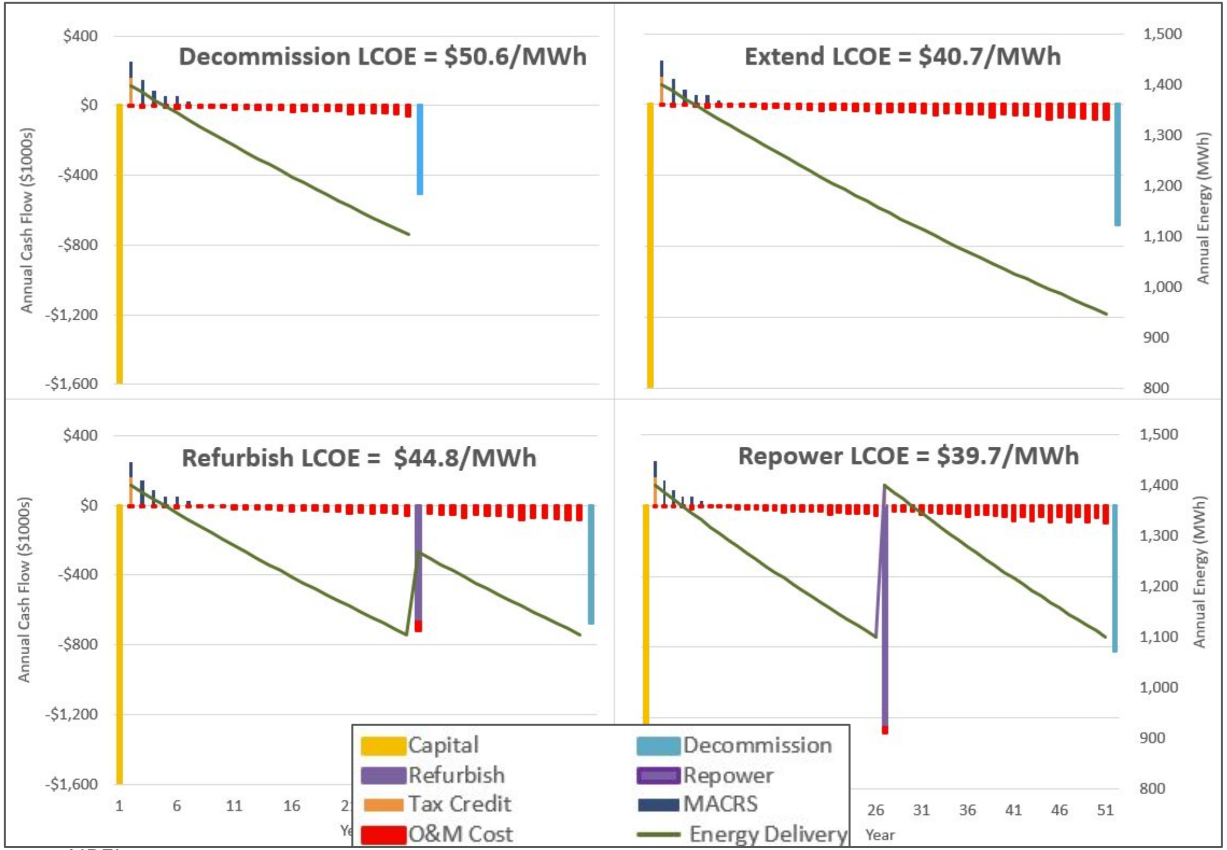
Figure Sources: NREL; IEC

CE approaches can lower cost of electricity over project lifetime for utility-scale solar



Source: NREL

Refurbish: reset recoverable degradation rate
Repower: reset total degradation rate (new panels)

EoL cost estimate as portion of LCOE: $3 - $7 /MWh

Key results:

- Decommissioning is most expensive option
- Repowering leads to lowest overall LCOE
- Simply extending lifetime in-place can substantially reduce costs

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Financing for recycling could take various forms

Fee-based

Raising funds for in state recycling efforts through installation and RECs fees

Ex. MD legislation that did not make it out of committee 2018-2020

Extended Producer Responsibility (EPR)

Makes manufacturer/distributor responsible for end of life disposal and costs.

Ex. Washington state EPR program, EU, South Korea

Reducing costs

Universal waste categorization can reduce costs of handling, transporting, & storing hazardous waste, but might not increase recycling

Ex. CA & HI consider PV panels UW, EPA rulemaking

Market-driven solutions

Landfill diversion regulation that administers fees/fines or other penalties for dumping PV waste into landfills

Ex. NC proposed legislation

Sources: NREL, Lee et al. 2023

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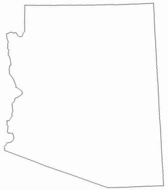
EPR-like Programs Proposed in Multiple States

NY - SB 7789 (2016)

EoL management program in which fees/charges to consumers not allowed

Education, outreach, communication provisions included



AZ - HB 2828 (2020)

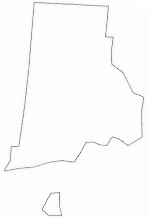
EoL management required by those who sell, lease, manufacture

Included landfill diversion policy

MN - HB 2909 (2014)

Program would include steps to reduce waste generation and promote recycling

Included MSW diversion policy



RI - HB 5525 (2021)

Manufactures required to submit plans to RI govt

Manufacturer can designate outside stewardship organization

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Sources: NREL

Other states are also exploring Circular Economy approaches to solar

North Carolina:

- Recommended that panels only be considered EoL when no longer functioning - observe waste hierarchy
- Utility-scale plants should anticipate EoL costs (collection, transportation, etc) as part of decommissioning planning
- SB568 (2019): utility scale decommissioning - panels must be reused or recycled

New Jersey:

- Recommends extending project life of utility scale solar, pushing beyond the typical 80% nominal power output
- Proposes secondary markets for underserved communities, donation
- Suggests adopting Universal Waste model for existing facilities or EPR program

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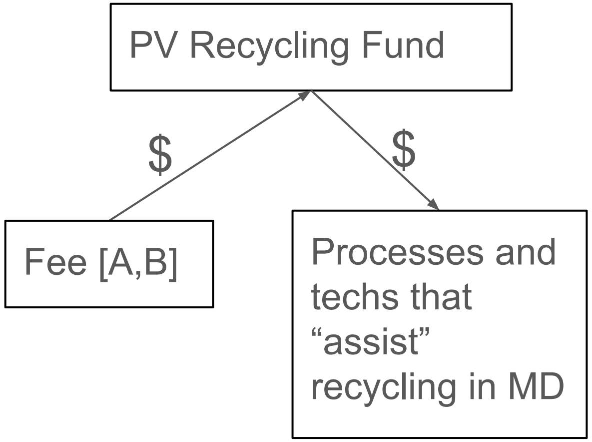
Sources: NC DEQ Report, NJ Solar Panel Commission Report

Two Previous MD legislative efforts to create PV recycling policies

HB 1242 (2018), **125** (2019), **165** (2020): PV recycling fees for PV Recycling Fund at MDE [1,2,3]

- 10% installation cost of PV system [A]
- 20% sale price of each first REC sold [B]
- Local govts (county, municipality) couldn't charge a different fee on installations (local revenue impacts)
- Slated to be cost neutral *overall* for the state



SB 891 (2020)

Directed MDE to develop stewardship program guidelines ("EPR")

Included provisions to establish reuse and recycling goals

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Sources: HB125, HB165, HB1242, SB 891

PV-ICE model is designed for solar materials analysis

Material	Purpose	Weight
Glass	Panel Surface	76%
Polymer	Encapsulant & backsheet foil	10%
Aluminum	Frame, Supports	8%
Silicon	Absorber	5%
Copper	Interconnects	1%
Silver	Contacts	0.1%
Tin and Lead	Solder	‘trace’

Bulk, semi-high value, high value

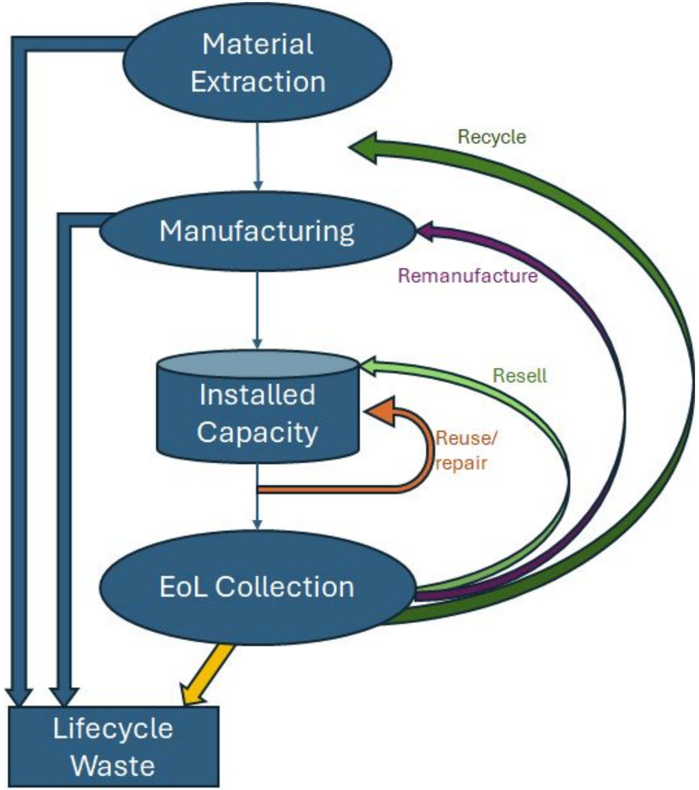
- PV-ICE allows evaluation of various EoL options and impact on waste streams
- Can adjust baseline parameters to reflect newer technologies
- We assume future solar deployment in Maryland is crystalline-silicon modules
- Glass is primary material by weight

Preliminary results

Source: PV-ICE

Model parameters enable representation of EoL policies

Model inputs:
- Recycling rates
- Re-use rates
- EoL/waste criteria
- Degradation rates



Model outputs:
- Waste generated (tonnage)

Modeling scenarios simulate different paths for deployment and EoL policy

Deployment Levels
BAU (w/ existing scaling rates): Continuation of current solar deployment trends (Source: EIA State Energy Data System)
Current Policies Scenario: Renewable Portfolio Standard (RPS) target of 50% by 2030. RPS Solar target: 14.5%. Scaling rates taken from Maryland's Climate Pollution Reduction Plan.
Current + Planned Policies Scenario: Proposed Clean Power Standard (CPS) of 100% by 2035. Scaling rates taken from Maryland's Climate Pollution Reduction Plan.

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EoL Policy Approaches
No policy: All panels landfilled.
Recycling mandate: 80% of materials by weight recycled starting in 2030, increasing to 85% in 2035. Similar to EU/South Korea EPR policies.
Circular economy: Assume 45% waste stream can be repaired or remanufactured, assume 20% reused. Recycling mandate for remainder of panels.

= 9 scenarios

Preliminary results

Preliminary results

Inputs used to create modeling scenarios

- Set parameter for when a panel reaches “**EoL**” - often when power output drops below 80%
- Change levels of future **deployment** to reflect BAU, CP, CPP
- Scale **recycling rates** to mimic EU regulations
- For CE sensitivity, alter **reuse, repair, and “stay in place”** parameters to reflect longer project lifetimes and prioritize repair/refurbish

Repair: “Percentage of modules which are repaired after premature failure from the field. This parameter is applied only to modules failed through the Weibull function (i.e. T50 and T90). Repaired modules are returned to the field and continue generating energy at their cohort specified degradation rate.”

Remanufacturing: “Percentage of collected end of life good modules which are disassembled for component remanufacturing (ex: recovering the front glass intact for use in a new module).”

Potential implications of modeling results

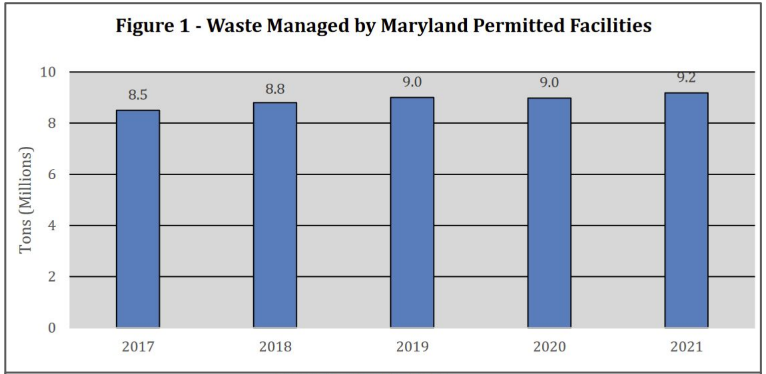
- Need for manufacturing, remanufacturing, recycling facilities
- Need for transport of new or used panels (for resale or remanufacture)
- Need to increase secondary markets, need for certification standards for used panels (e.g. SERI R2v3 Standard)
- Impact on landfills under different strategies

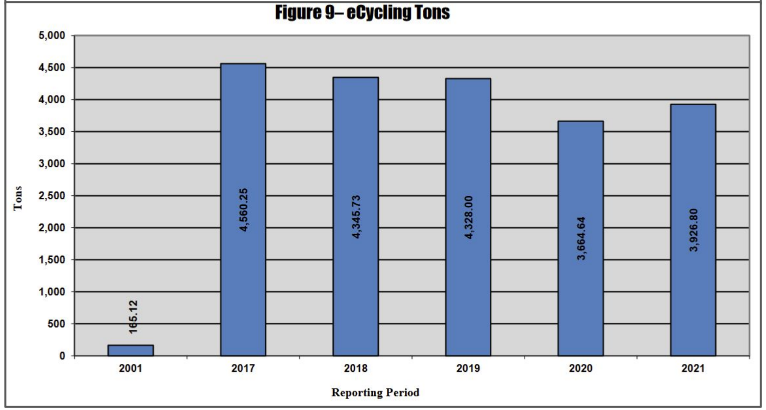
Preliminary results

Landfills in Maryland: Capacity and E-waste

- From EPA Waste Estimation tool:
  - 2040 (early loss) → 103,000 tons
  - 2050 (early loss) → 237,000 tons

- *Questions to consider:*
  - How many landfills accept solar panels?
  - Possibility of waste being shipped outside of MD for disposal in landfill?
  - Solar panels being covered by eCycling (CED)?





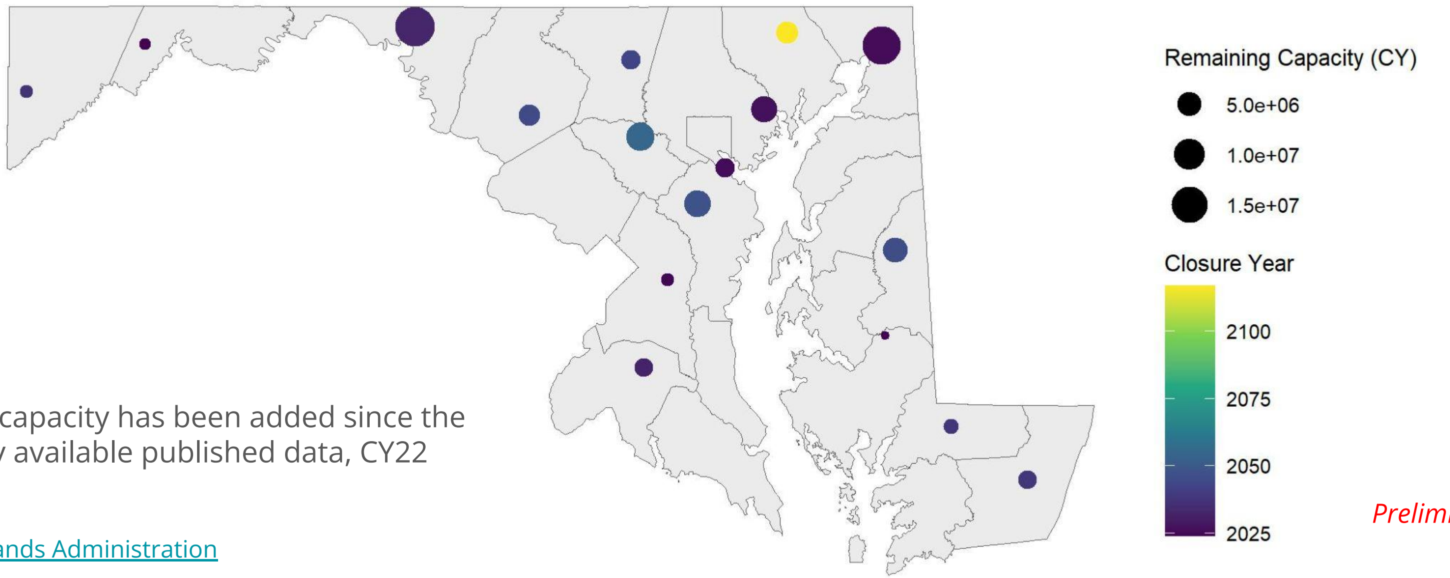
Preliminary results

Source: EPA, MDE [Lands Administration]

Landfills in MD: Location and County Perspective

Feedback from county recycling coordinators:

- 6 responses so far, waiting on others
- Some commented they wouldn't take large amounts of panels, some said they wouldn't take any (landfill, transfer station)
- No one mentioned having county-level policies for recycling solar
- A couple mentioned waiting on MDE guidance



*Note: more capacity has been added since the most recently available published data, CY22

Preliminary results

Source: EPA, MDE [Lands Administration]

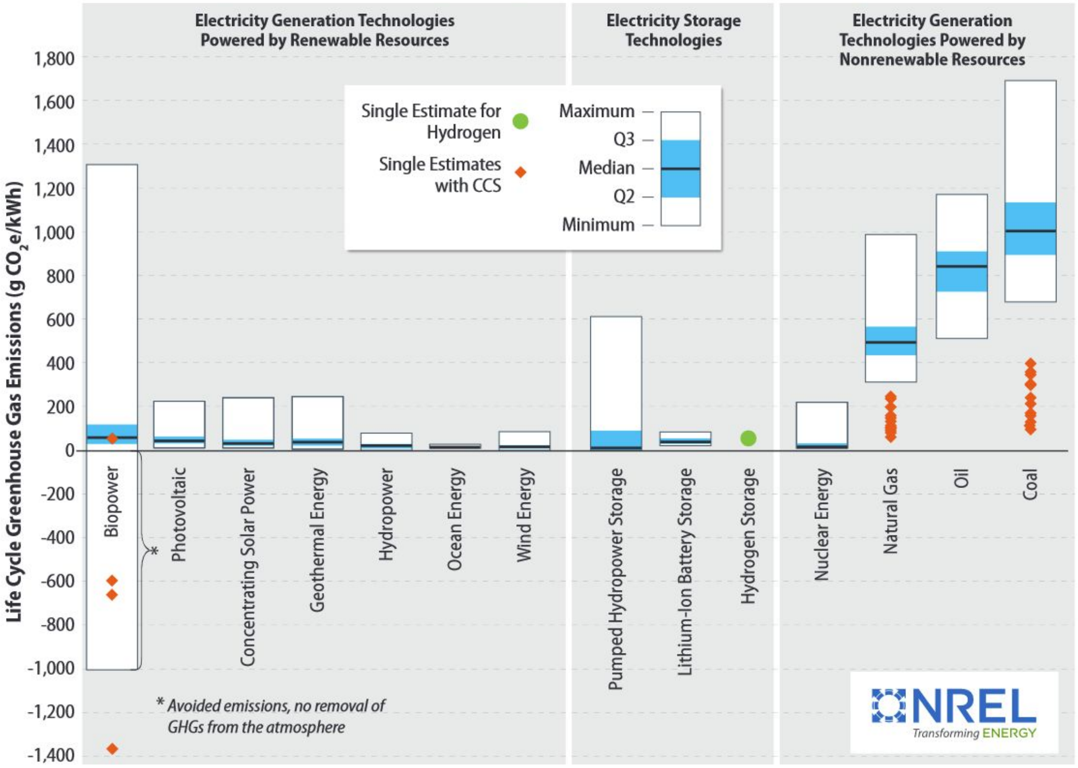
Next Steps

Impact assessment of model results:

- Utilizing existing LCAs, we will quantify as many environmental impacts as possible under the modeled scenarios
- GHGs, PM, metals/minerals resource use, etc.
- Comparisons with other technologies will be provided when data is available

More outreach to counties, solar installers/developers

Figure 2. Life cycle greenhouse gas emission estimates for selected electricity generation and storage technologies, and some technologies integrated with carbon capture and storage (CCS).



Preliminary results

Source: NREL

Thank you!

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