

# Advancing the Circular Economy for Renewable Technologies: Regulatory Innovations for PV Solar Recycling in the Asia-Pacific Region

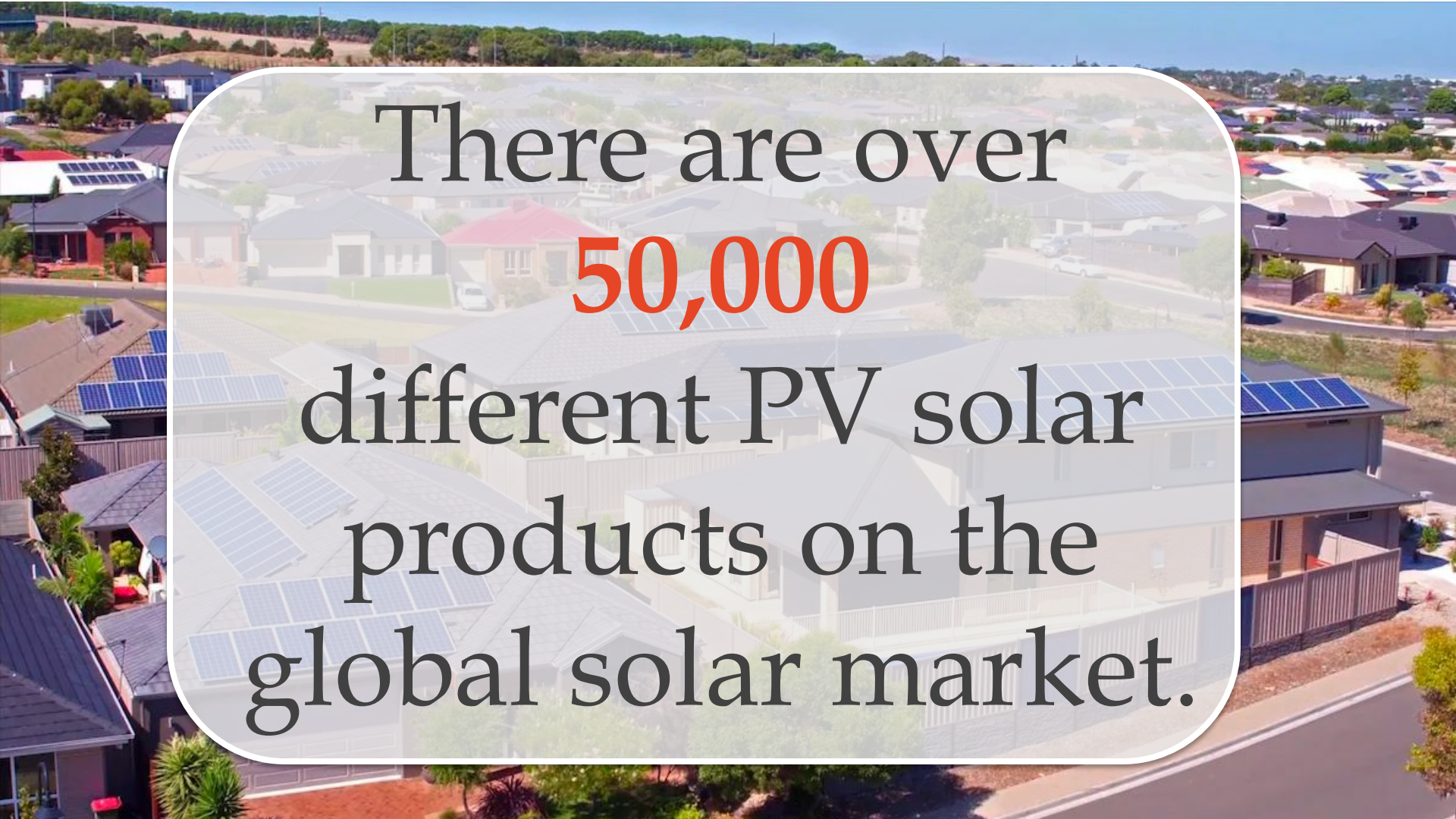
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THE UNIVERSITY OF  
**SYDNEY**

CRTCOS 00026A

Project Funded by the Australian Research Council Grant: *Circular Clean Energy Regulation: Solving the PV Solar Waste Crisis* ARC DE240100001 (2024-2027).

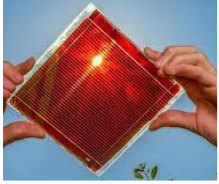
An aerial photograph of a suburban neighborhood with numerous houses. Many of the houses have solar panels installed on their roofs. The houses are mostly single-story or two-story homes with various roof colors and styles. The surrounding area includes trees, lawns, and some commercial buildings in the distance. The sky is clear and blue.

There are over  
**50,000**  
different PV solar  
products on the  
global solar market.



# Recent solar innovations

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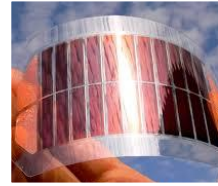
Perovskite Solar Panels



Tandem Solar Cells



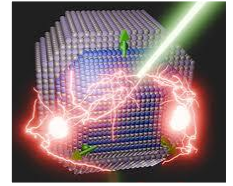
Bifacial Solar Cells



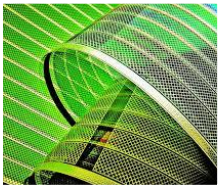
Organic Solar Cells



Building Integrated Photovoltaics



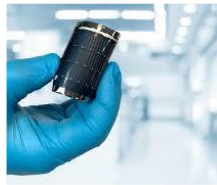
Quantum Dots



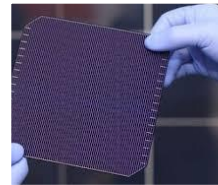
Organic Polymers



TOPCon Technology



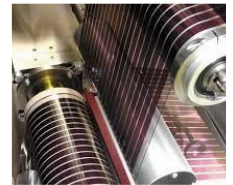
CIGS



Graphene



Sun-Tracking Solar Panels

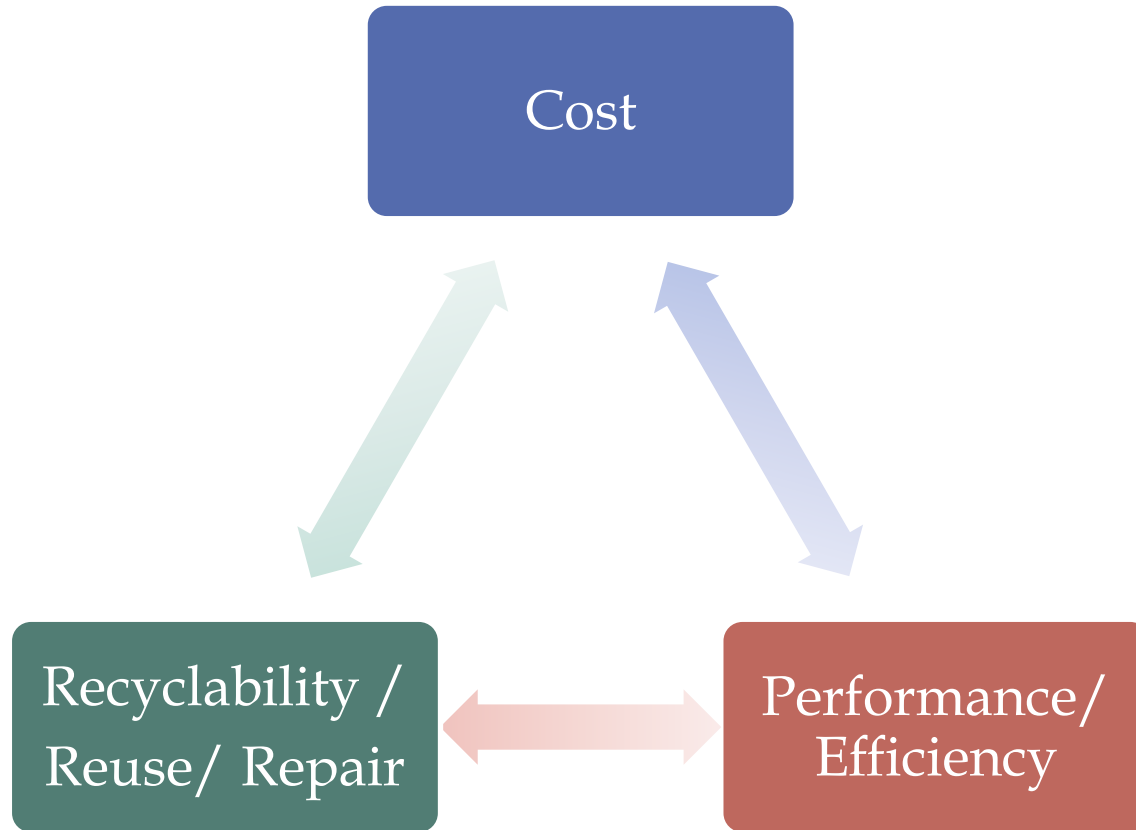


Printable Solar Cells



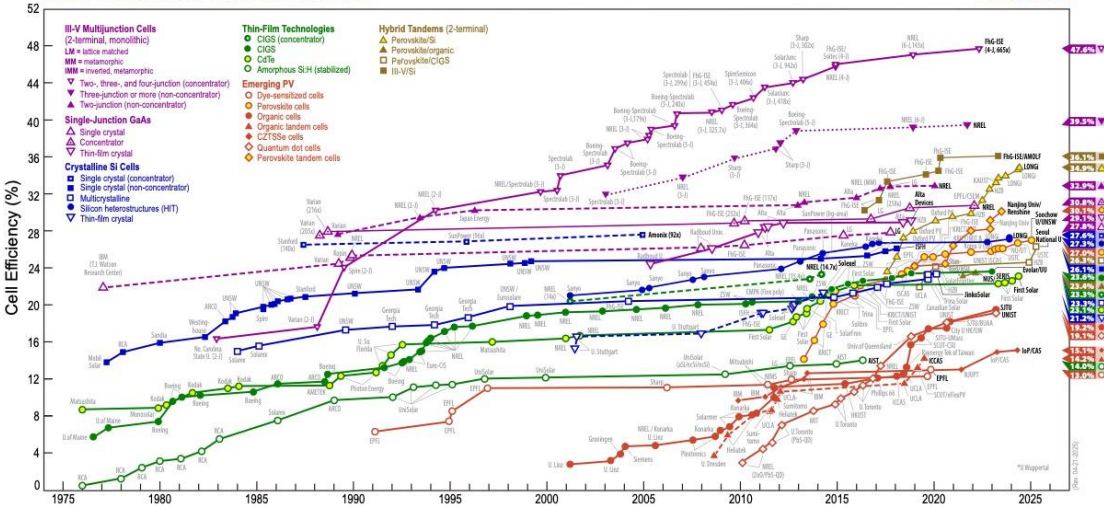
Solar Skins

# Design trade-offs in new solar innovations



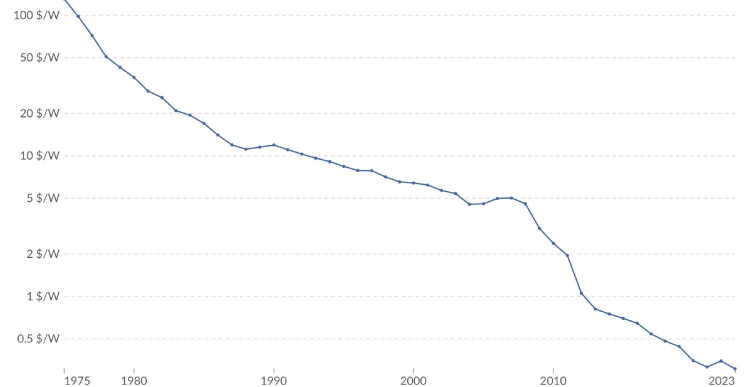
# Focus of technological innovations

## Best Research-Cell Efficiencies



## Solar (photovoltaic) panel prices

This data is expressed in US dollars per watt, adjusted for inflation.




Data source: IRENA (2024); Nemet (2009); Farmer and Lafond (2016)

Note: Data is expressed in constant 2023 US\$ per watt.

OurWorldInData.org/energy | CC BY

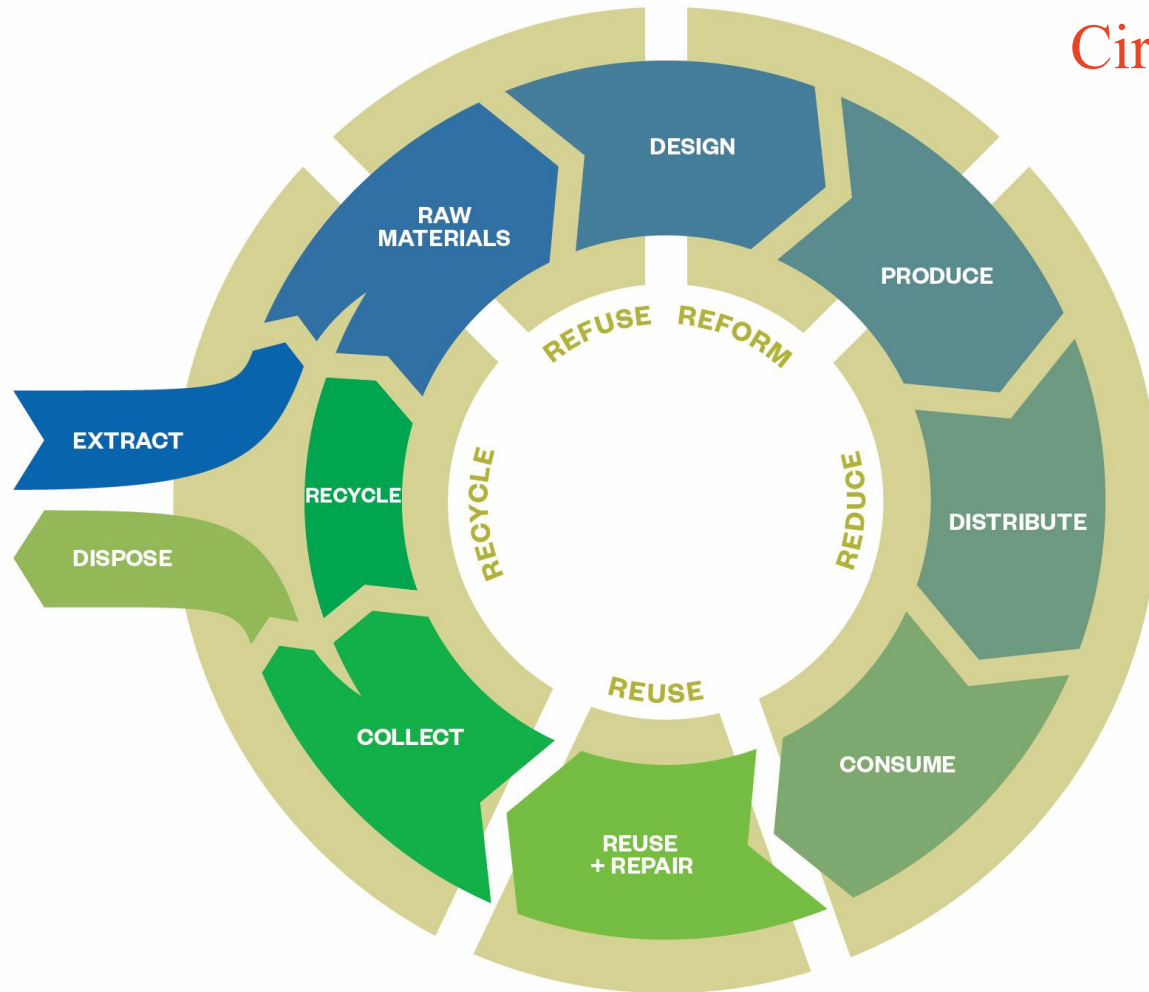


The background image shows a large pile of discarded solar panels and components at a landfill site. The panels are broken, bent, and scattered across a dirt and debris-covered ground. Some panels are still intact but lying flat, while others are crumpled or partially destroyed. The scene illustrates the problem of solar waste disposal.

Currently, most PV solar products go to landfill  
at EoL rather than being  
reused/repaired/recycled.

Solar waste est. to create 78 million tonnes of  
toxic waste in landfill globally by 2050  
(IRENA, 2016).

# Circular Economy



## 7 Fundamental challenges at EoL for Solar PV

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- Fluctuating volumes of solar being retired (unpredictability due to early retirement)
- Lack of available data
- Need for economies of scale
- Diversity of products/lack of international product design standards
- Lack of available and affordable testing for 2<sup>nd</sup> hand market (reuse/repair)
- Lack of recycling facilities
- Cost of recycling + value of recycled materials vs cost of landfill

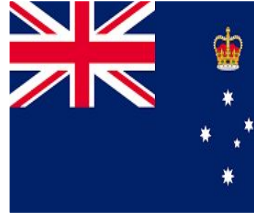


# Selected regulatory solutions



European Union

Directive  
2012/19/EU of  
the European  
Parliament and  
of the Council of  
4 July 2012 on  
waste electrical  
and electronic  
equipment  
(WEEE) (recast)



Victoria, Australia

Environment  
Protection Act  
1970



California, USA

Photovoltaic  
modules (PV  
modules) –  
Universal Waste  
Management  
Regulations  
2021  
  
Hazardous  
Waste Control  
Law



South Korea

Enforcement  
Decree of the Act  
on Resource  
Circulation of  
Electrical and  
Electronic  
Equipment and  
Vehicles  
(Resource  
Circulation Act)

# Advantages and Disadvantages of Regulatory Options

Regulatory option	Advantages	Disadvantages
Mandatory Extended Producer Responsibility	Creates market scale and should drive down cost	Increases upfront costs for consumers
Voluntary EPR	Provides marketing benefits for participants	Unlikely to capture most of the market
Landfill Bans	Prevent critical minerals and lead/cadmium going to landfill	Without recycling facilities, creates a long-term storage issue.
Mandatory Recycled Content Requirements	Provides a market for reprocessed PV solar materials	Difficult unless domestic solar PV manufacturing and recycling is at scale.
Incentivising Private Sector Participation	Create industry buy-in and domestic capability	Who pays?
Design Standards	More uniform processes for repair/recycling	May impede innovation and competition
Interoperability	Prevent early retirement of componentry	Lack of industry support
Testing Facilities	Urgently needed to support the repair/reuse market.	Hard to justify cost without government intervention unless sufficient scale/2 <sup>nd</sup> hand market development

## Circular clean energy regulation

A fundamental re-orientation of our regulatory framework governing renewable technologies to a holistic life cycle approach that encompasses the potential for recycling and critical mineral recovery at end of life, and principles of energy justice.

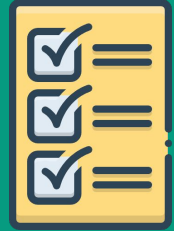


## Some key questions for legislative design

1. Who bears the legal onus to manage the end of life of renewable technologies and on what basis is that responsibility ascribed?



2. What ought regulation require the liable entity to do at the end of life?



3. How and when the mandated activities are funded?



4. What happens if the liable entity cannot recycle their renewable technology?



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# Renewable Energy Law

An International Assessment

Penelope Crossley

