Faculty of Engineering
School of Photovoltaic and Renewable Energy Engineering

Scoping Study: Solar Panel End-of-Life Management in Australia

12th July 2024, SPREE Seminar

Dr Rong Deng

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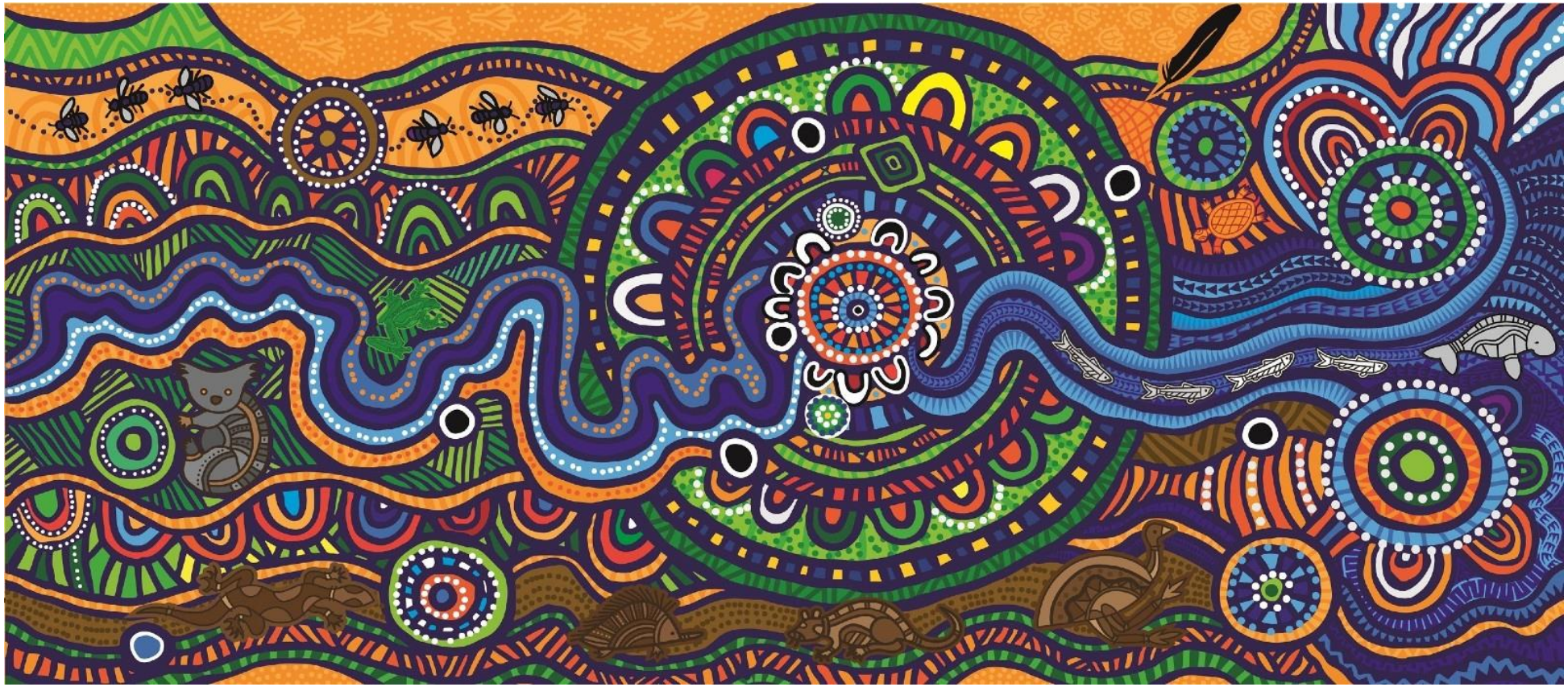

I begin today by acknowledging the Traditional Custodians of the land on which UNSW Kensington campus stands, the Bedegal people, and pay my respects to their Elders past, present, and emerging.

Dr Rong Deng

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- PhD, 2021, Photovoltaic Engineering, UNSW. “End-of-life management and recycling of silicon photovoltaic modules: towards a circular economy”.
- Part-time MBA Candidate, 2023-ongoing, UNSW AGSM
- Bachelor of Engineering (Honours) in Photovoltaic and solar energy engineering, UNSW

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ACAP

AUSTRALIAN PV INSTITUTE

Importance of End-of-Life Management of PV Systems

43%
carbon reduction emission target by 2030

82%
Renewable energy target by 2030

Millions tonnes
of end-of-life solar panels

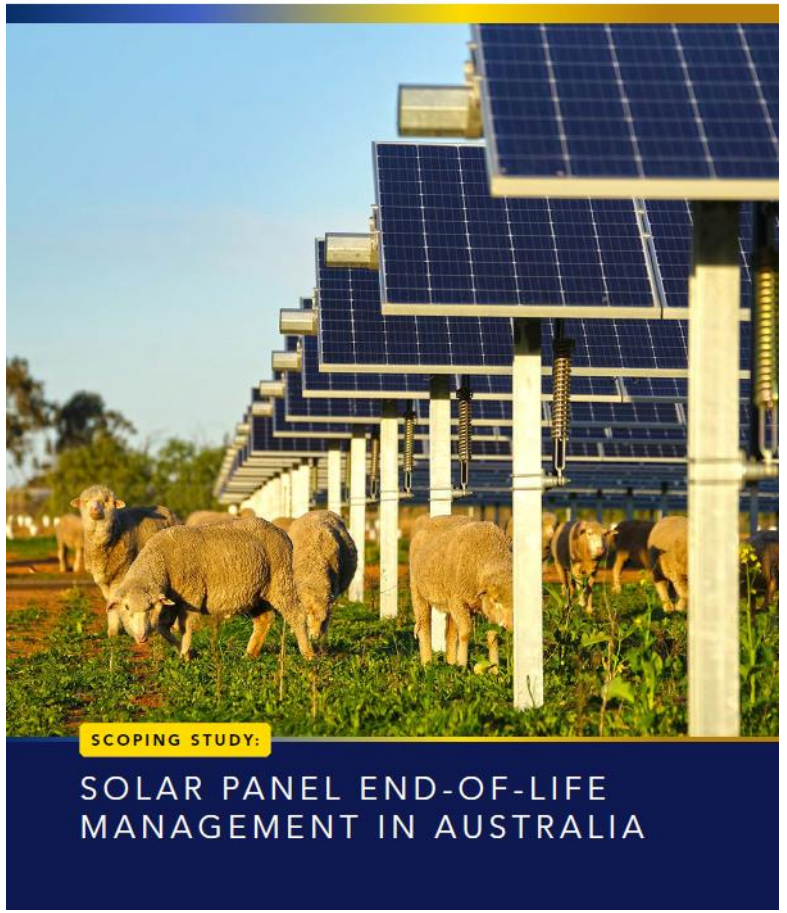
Unclear waste category

Lack of Management Framework and Infrastructure

National Waste Policy Action Plan Target

Scoping Study: Solar Panel End-of-life Management in Australia

- Neoen partnered with the Australian Centre of Advanced Photovoltaics (ACAP), centred hosted by UNSW and co-funded by ARENA, to deliver this scoping study: *solar panel end-of-life management in Australia*.
- The study provides an in-depth analysis of the current PV recycling landscape, market opportunity, best practice and most cost-effective strategies to manage solar panels end of life in Australia.



Scoping Study: Solar Panel End-of-life Management in Australia

- Funded by: Neoen and ACAP.
- Research: ACAP and rCITI.
- Insights and review panel: Neoen (insights from operation and management in utility-scale PV), Veolia (insights on the current challenges faced by the recycling industry and what is required to move forward in Australia), ACT NoWaste (insights in relation to the ACT's waste and circular economy policy context).

Media: imminent challenge of discarded solar panels

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Energy

Solar panel waste to reach crisis levels in next two to three years, Australian experts warn

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Challenge to stop solar panels becoming a 'waste mountain'

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Wednesday, April 10, 2024

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Australia's rooftop solar waste problem is hurtling towards 1.2 gigawatts a year

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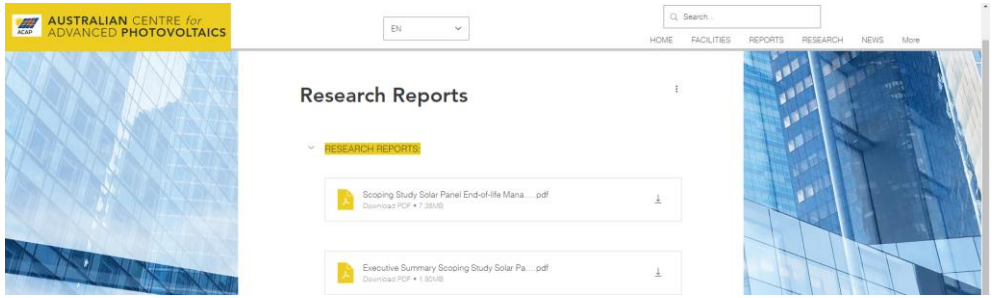
Outcomes

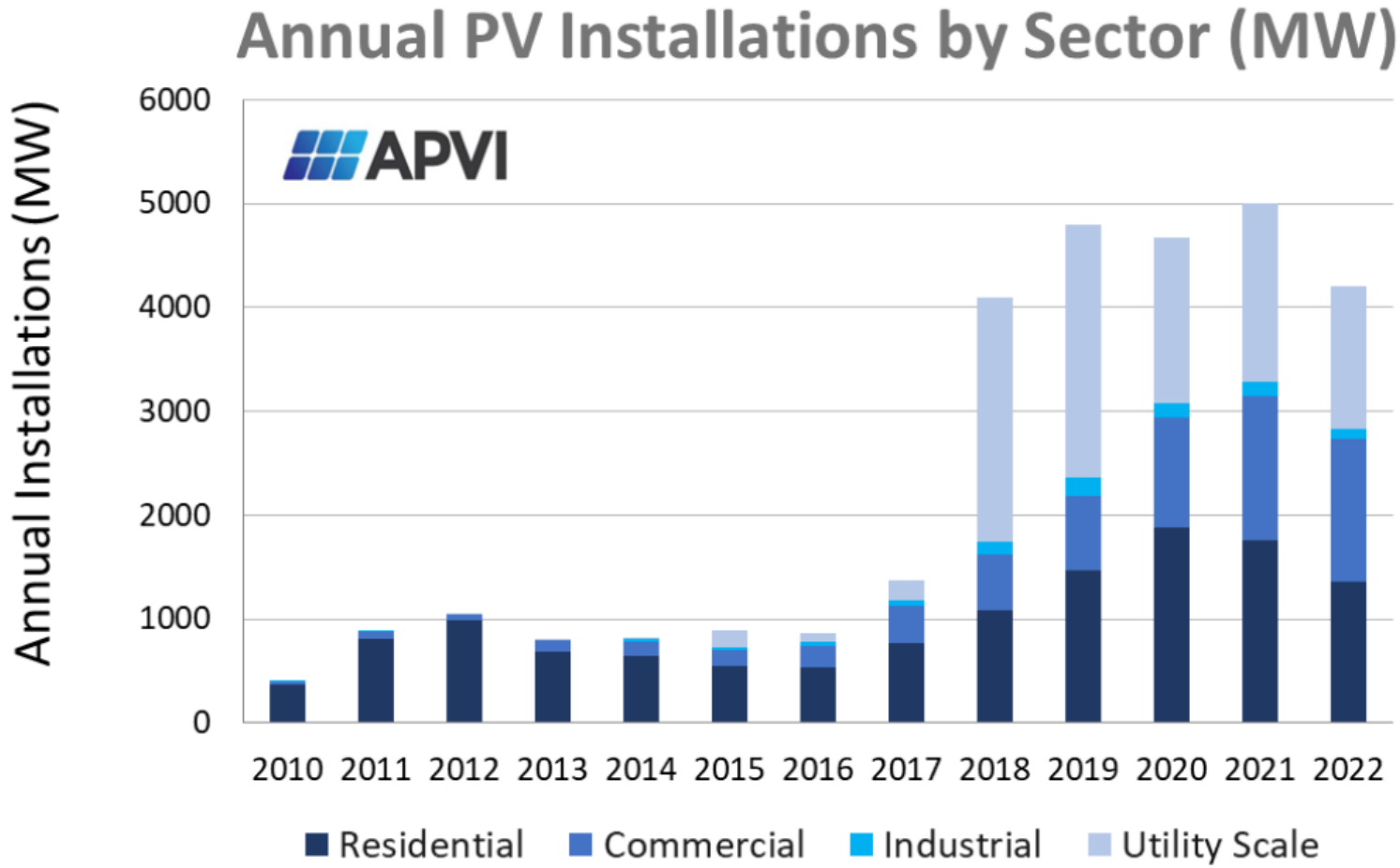
The project achieved the following outcomes:

1. Assess the volume and location of end-of-life solar panels in Australia from 2023 to 2035.
2. Map the optimal locations, treatment capacities and associated logistic networks to for large-scale PV waste management facilities in Australia for the 2023-2035 period.
3. Analyse the cost-benefits of module recycling and reuse technologies for Australia to understand the technical, investment and market requirements to establish domestic PV recycling industry.
4. Highlight best practice of PV end-of-life management policy frameworks and businesses.
5. Develop a case study for the ACT Region
6. Deliver a 12-year industry roadmap (2023-2035) bringing results from all above that the industry can take as a step-by-step guidance to sustainably deal with PV waste in Australia.

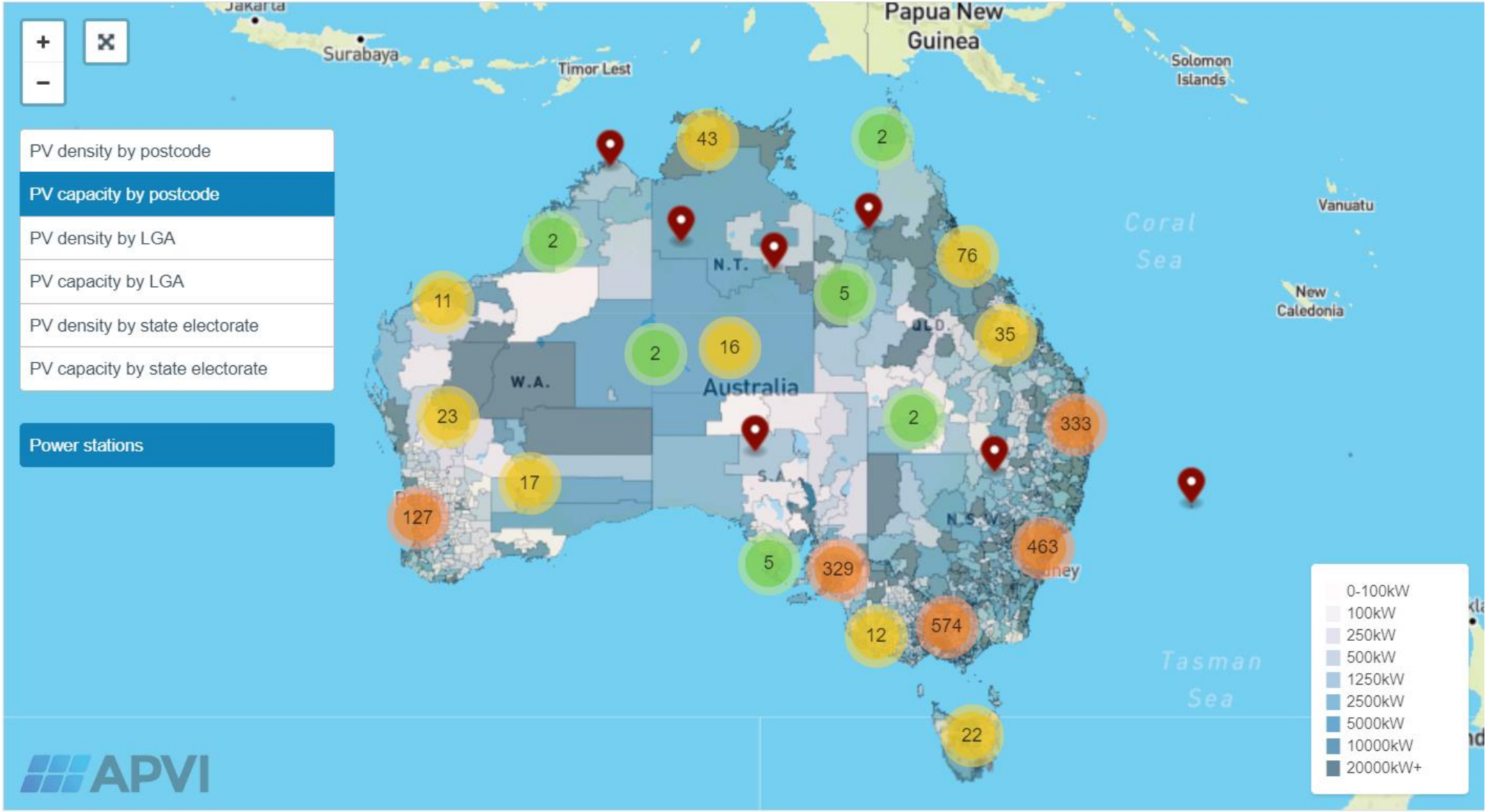


Australia PV market

Australia holds a world leading position in solar deployment and integration. By the end of 2023 Australia has reached 34GW of installed capacity. One in three Australian homes have PV.



Australia PV market



https://pv-map.apvi.org.au/historical

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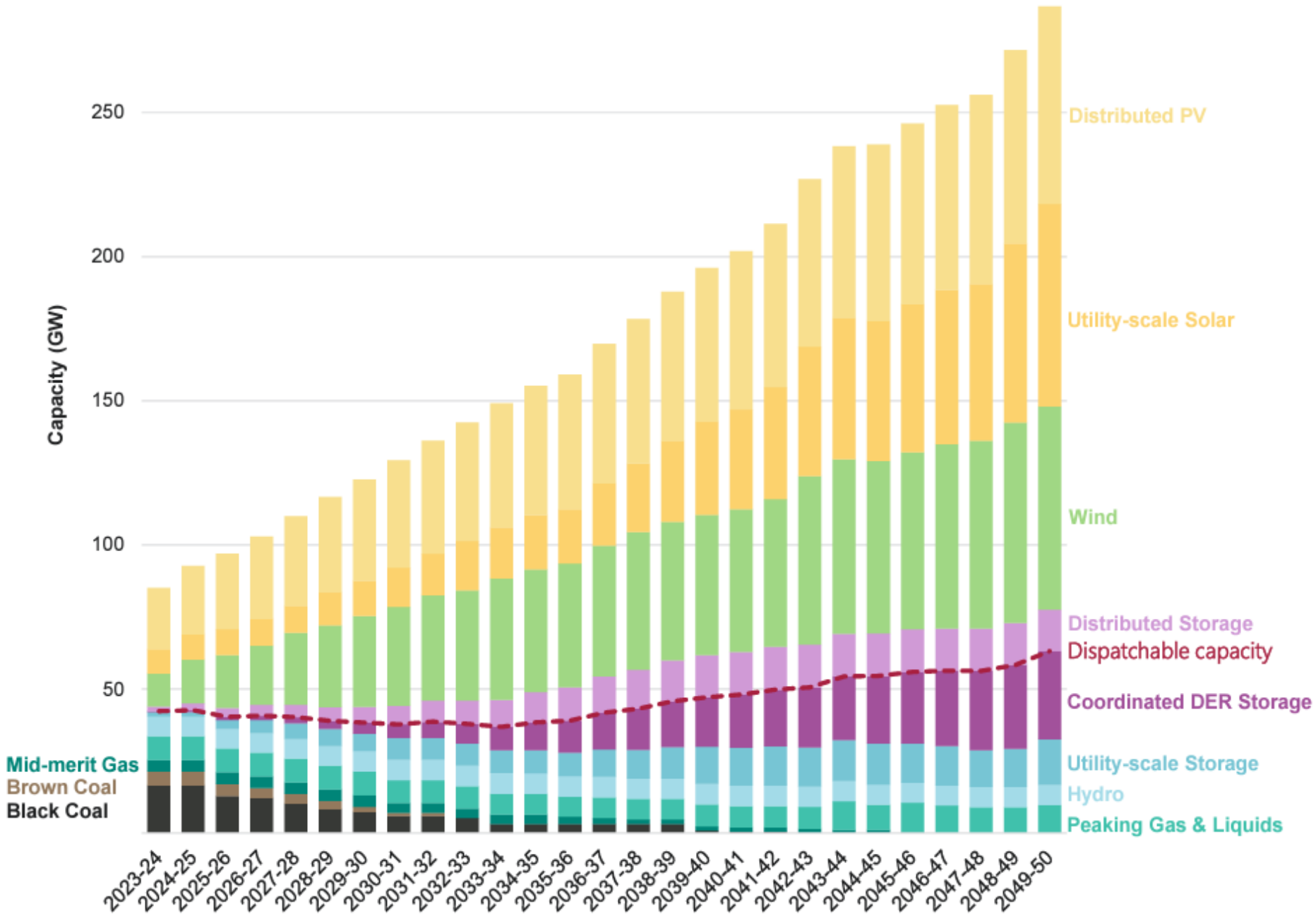
Figure 1 Forecast NEM capacity to 2050, *Step Change* scenario



2022 Integrated System Plan June 2022, AMEO

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Australia PV panels practical lifetime

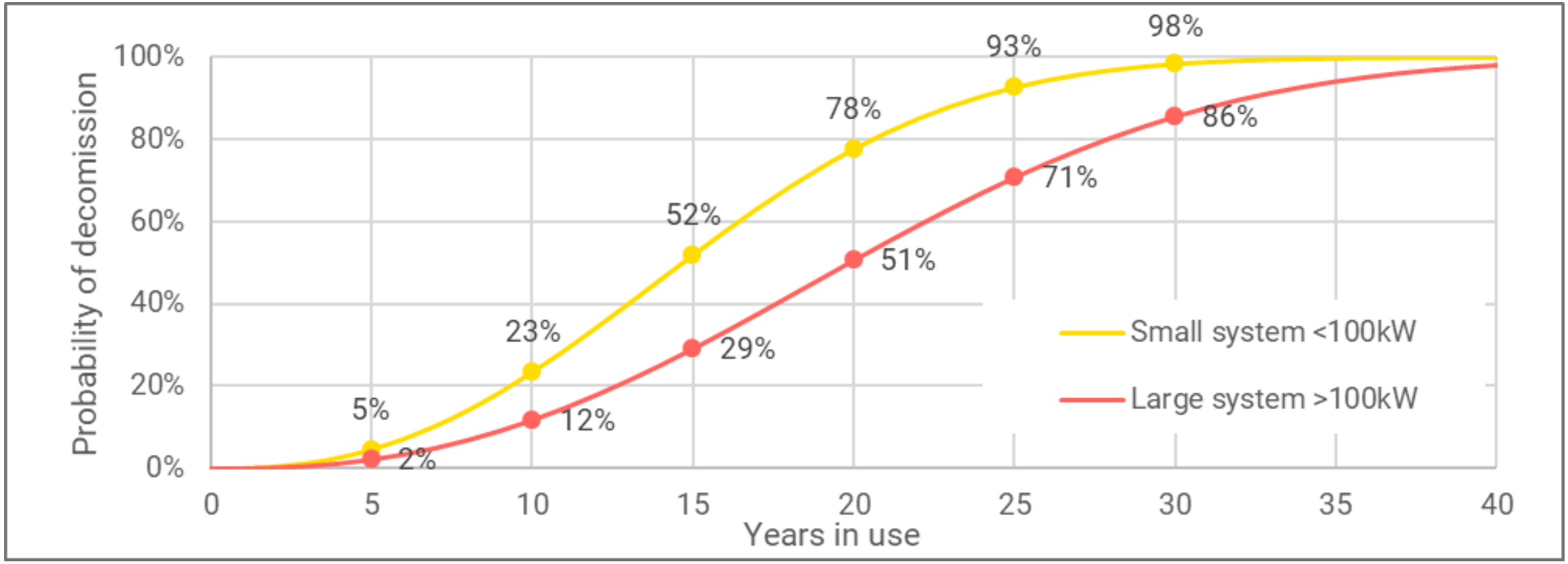
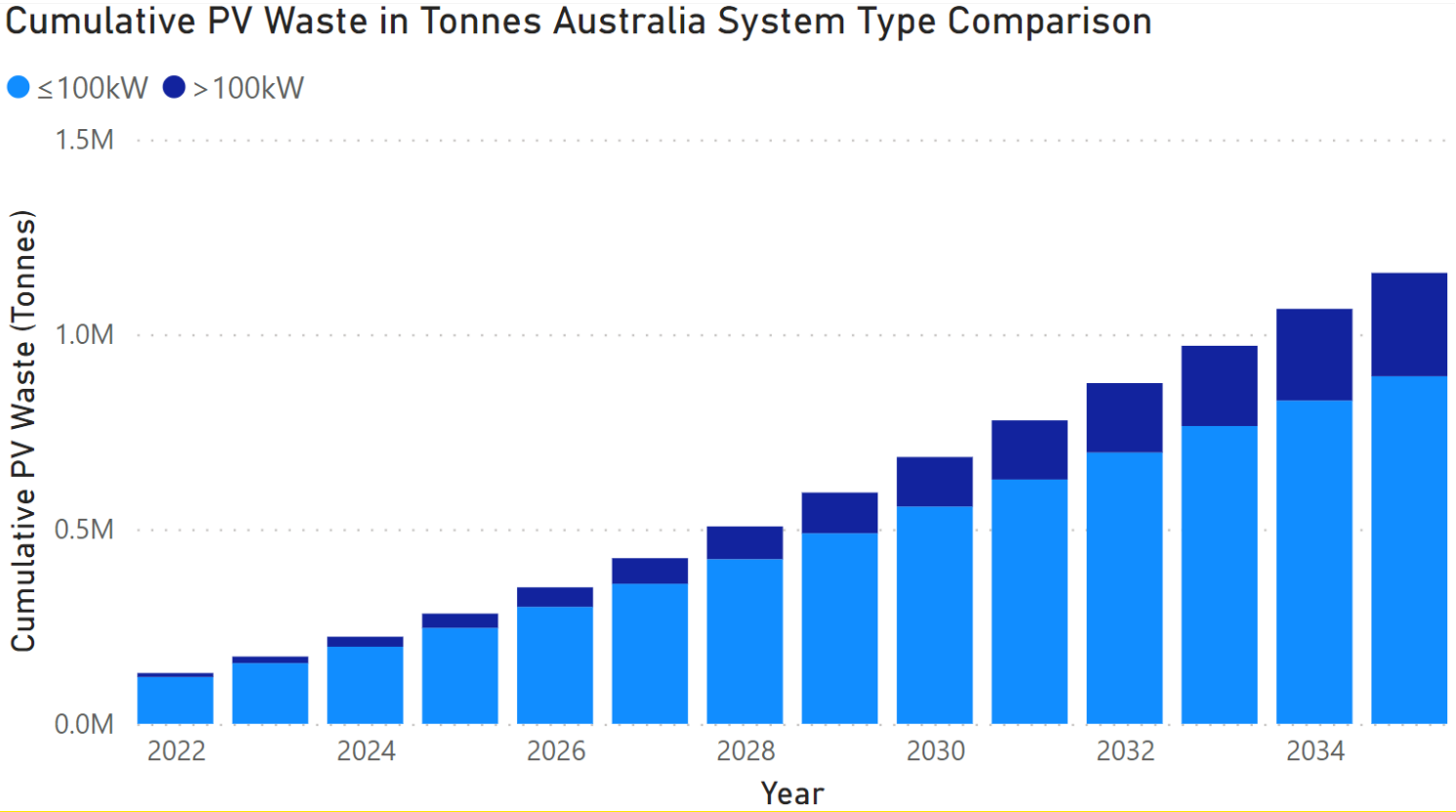


Figure: Solar panel lifetime estimates, represented by Weibull functions.

1. What is the volume of end-of-life panels in Australia?

On an annual scale, waste volume is expected to surpass 50,000 tonnes in 2025 and could reach approximately 100,000 tonnes, equivalent to 1.2 GW per year, from 2030 to 2035 nationwide. Cumulative volume will reach 1 million tonnes by 2035. Significantly, more than 80% of the decommissioned solar panels by 2030 are projected from small-scale distributed PV systems.

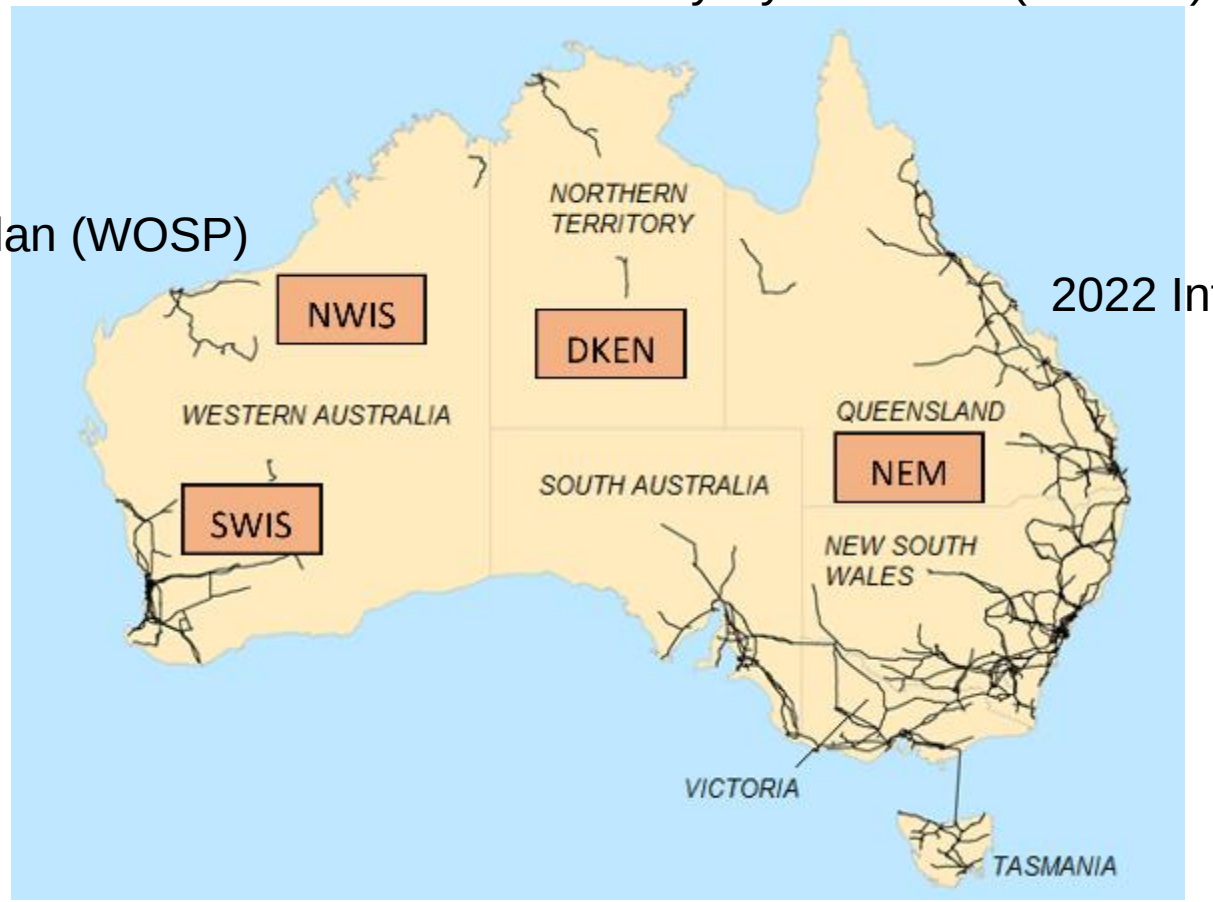


Australia Solar Panel Waste Volume Forecast – long term projection

2021 Darwin-Katherine Electricity System Plan (DKESP)

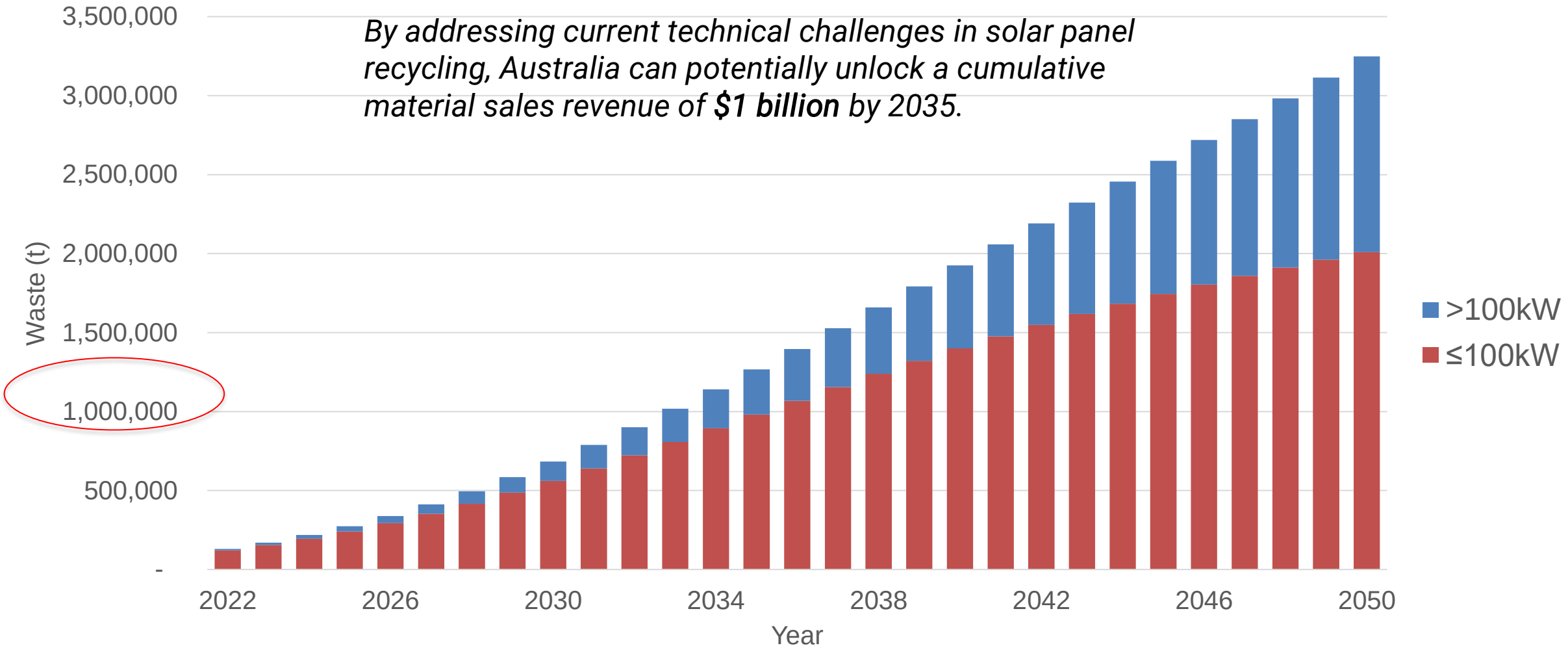
2020 Whole of System Plan (WOSP)

2022 Integrated System Plan (ISP)



Electricity Network in Australia including the three grids: NEM, SWIS and NWIS (WEM), and DKIS, adapted from Andrews (Andrews, 2017).

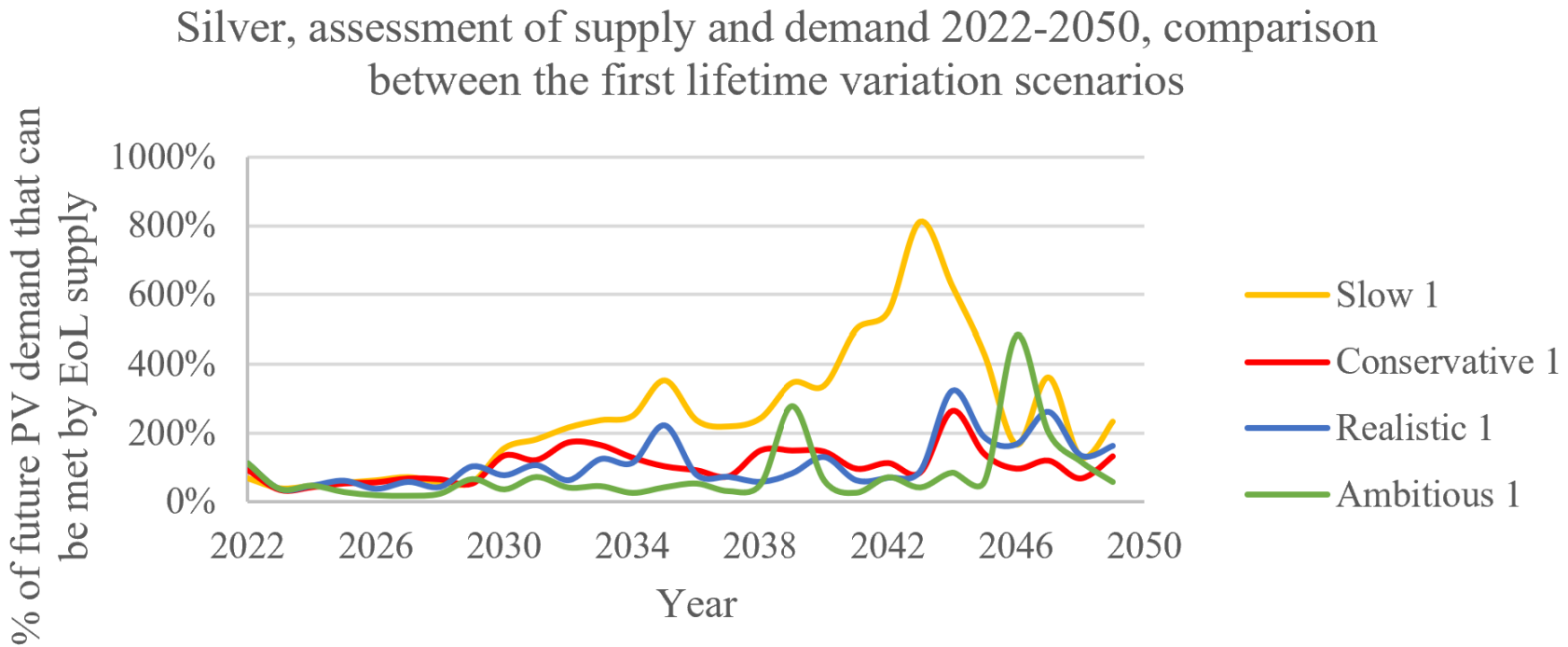
Australia Solar Panel Waste Volume Forecast – long term projection



Tan, V., Deng, R. and Egan, R., 2024. Solar photovoltaic waste and resource potential projections in Australia, 2022–2050. Resources, Conservation and Recycling, 202, p.107316.

Australia Solar Panel Waste Volume – long term resource potential

- Closed-loop potential (Al frame, Ag)
  - 30% in 5 years, 50% in 15 years, 100% in 25 years
- Initial waste from current installations → begin planning EoL management now.



2. Where will the issue of waste start to escalate?

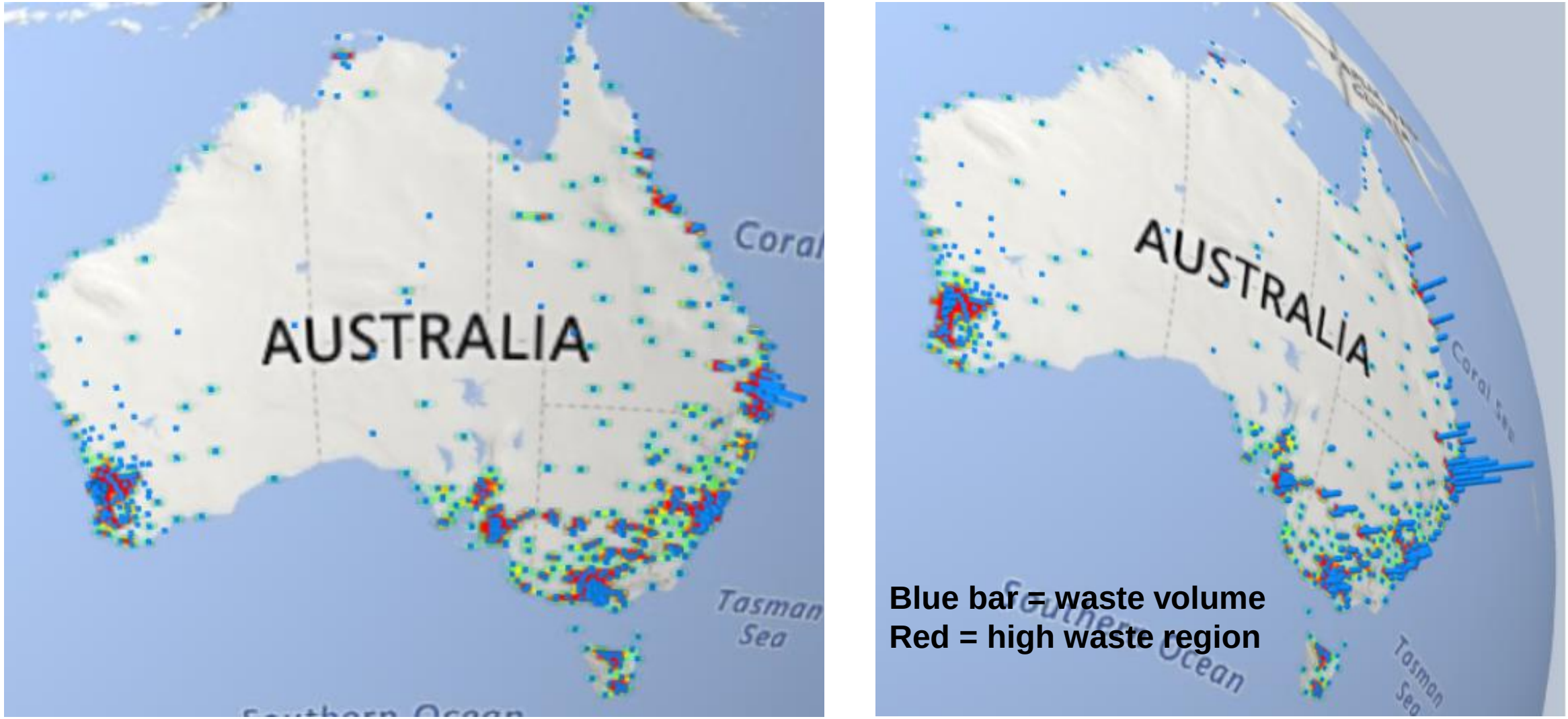


Figure: 3D bar maps showing projected cumulative PV waste (in tonnes) generated in each LGA in 2030.

Where will the issue of waste start to escalate?

- While large-scale solar farms in regional and rural Australia have no decommissioning plans before 2030, the bulk of this waste will cluster around major Australian cities: **Sydney, Melbourne, Brisbane, Perth, and Adelaide**. This issue is starting to manifest either currently or within the next 2 - 3 years, in contrast to some reports forecasting a crisis by 2030.

Class 1: Current high waste areas

Class 2: Emerging high waste areas

Class 3: Future high waste areas

Class 1	Class 2	Class 3
Sydney, NSW	Murrumbidgee, NSW	Canberra, ACT
Brisbane, QLD	Balranald, NSW	Toowoomba, QLD
Gold Coast, QLD	Dubbo, NSW	
Moreton Bay, QLD	Newcastle, NSW	
Adelaide, SA	Whitsunday, QLD	
Melbourne, VIC	Townsville, QLD	
Perth, WA	Sunshine Coast, QLD	
	Western Downs, QLD	
	Mildura, VIC	

3. Where should large-scale PV waste management facilities ideally be located to best handle the anticipated waste volumes?

- The proposed facilities ensure national coverage with minimum logistic costs.

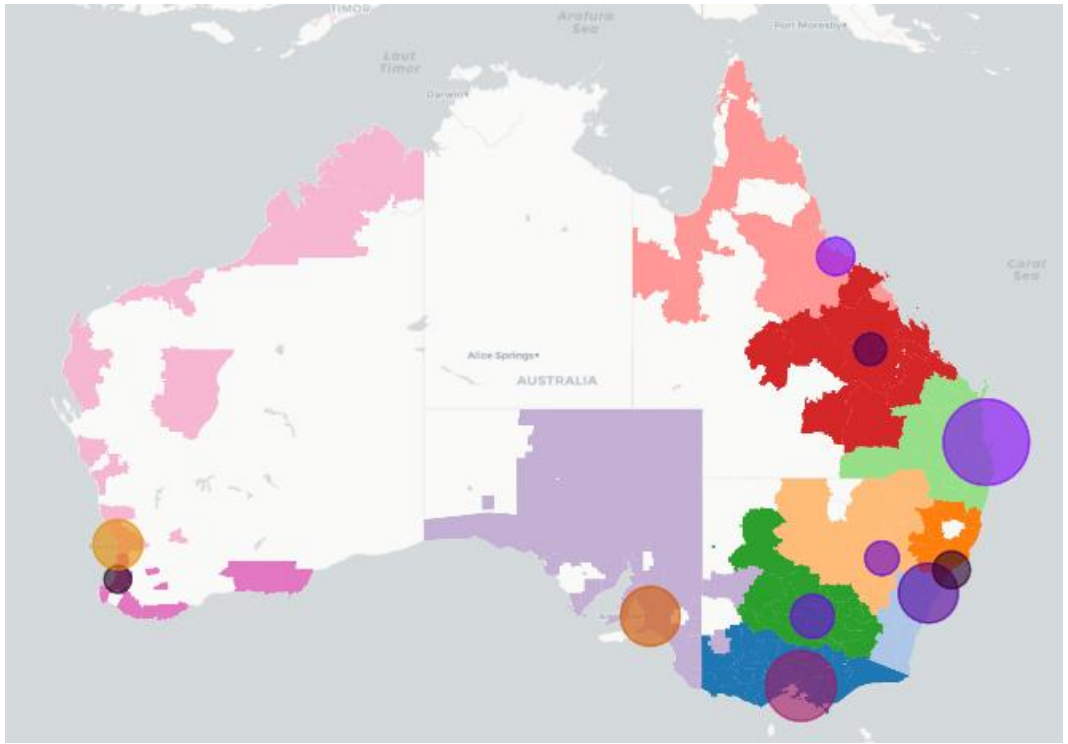


Figure: The optimal locations to establish large-scale solar panel waste treatment facilities in Australia.

Location	Expected waste volume (tonnes per year)		
	2023	2029	2035
Brisbane, Queensland	10,000	20,000	20,000
Melbourne, Victoria	7,000	14,000	14,000
Sydney/Penrith, New South Wales	5,000	10,000	11,000
Adelaide/Adelaide Hills, South Australia	5,000	9,000	9,000
Perth, Western Australia	3,000	7,000	7,000
Dubbo/Wellington, New South Wales	2,500	7,000	9,000
Townsville, Queensland	2,000	5,000	5,000
Newcastle, New South Wales	2,000	4,000	5,000
Murrumbidgee, New South Wales	1,500	4,000	4,000
Central Highlands, Queensland	1,500	2,000	2,500
Busselton, Western Australia	1,000	1,000	1,000

3. Where should large-scale PV waste management facilities ideally be located to best handle the anticipated waste volumes?

- Metropolitan facilities will have access to more than 70% of the PV waste generated by 2030.
- Australia has a unique advantage in starting a new PV end-of-life facilities in major cities, as more than 70% of PV waste is centralised near metro regions with supporting infrastructure, including aluminum smelting and recycling, glass recycling and manufacturing, and downstream metal refiners.

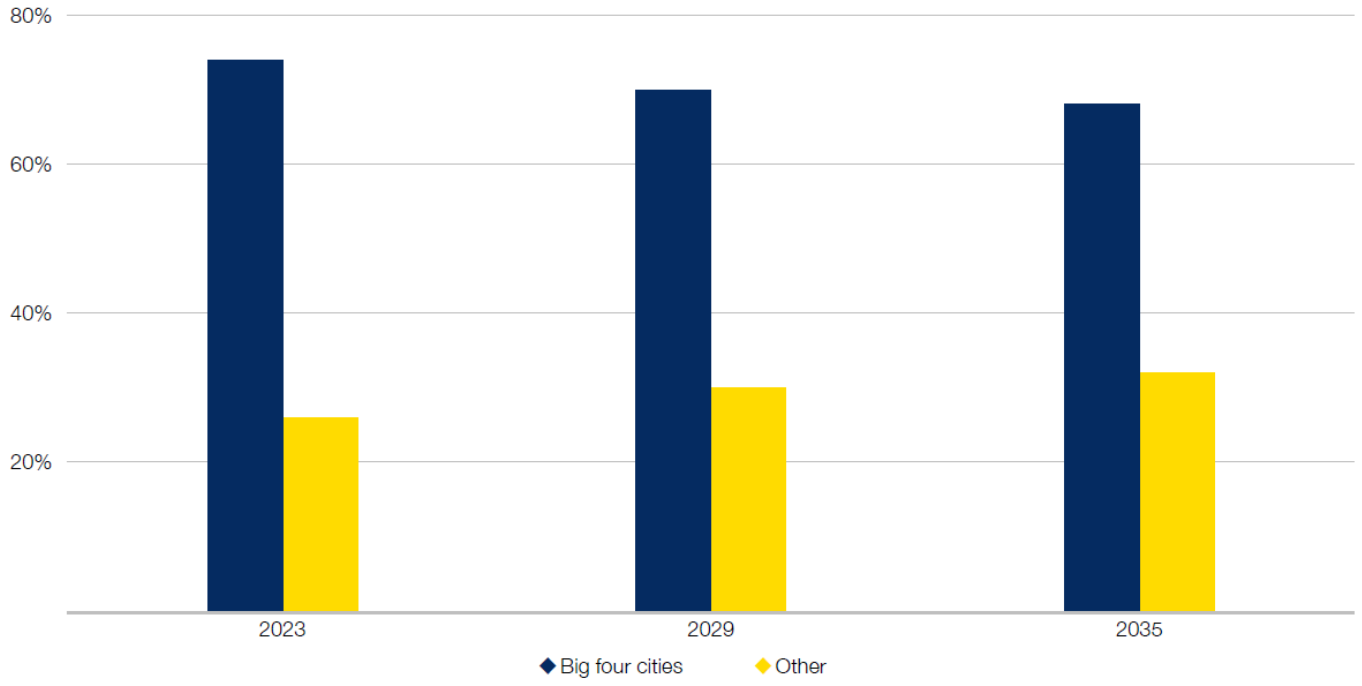
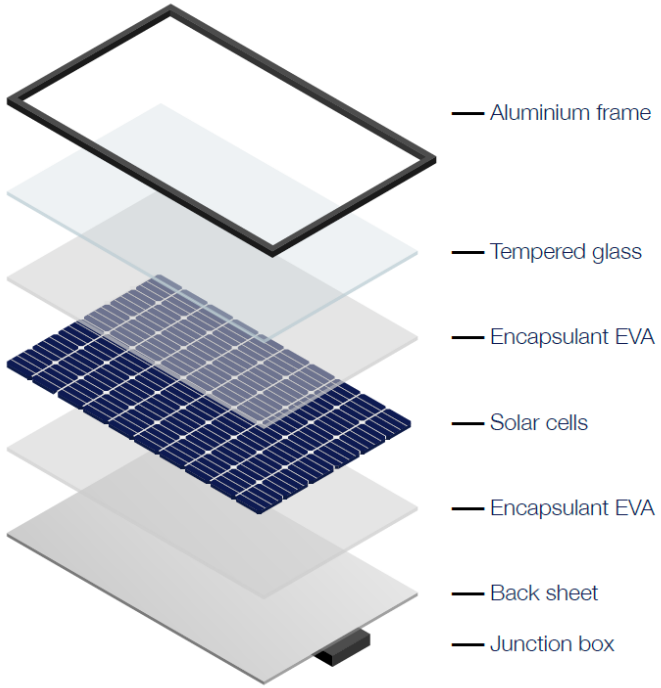
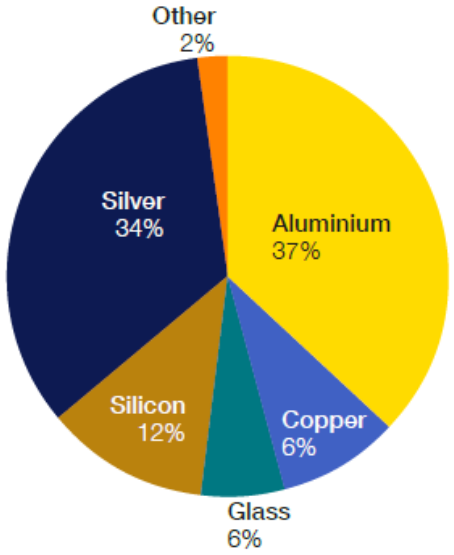


Figure: Comparison of treated volume in proposed metropolitan facilities vs others.

4. Are solar panels recyclable? Reusable?

- On average, over $20 worth of materials can be recycled from a typical 20-kg solar panel. Cumulative material value of $1 billion by 2035 in Australia.
- Value of reuse is unknown as it's hard to predict how much people are willing to pay for the second-hand panel without warranty.





Component	Material	Weight	Price ($/kg)
Solar cells	Silicon	3-5%	3.1 - 3.8
	Silver	0.03%-0.05%	746 - 1084
Ribbon	Copper	0.8%	7 - 10
	Tin	0.1%	22
	Lead	0.01%	3
Frame	Aluminium	16-20%	2.1 - 2.8
Glass	Glass	67-70%	0.06 - 0.13
Junction box	Copper	0.3%	7 - 10
Encapsulant	EVA	6-7%	Negligible
Backsheet	PVF/PET	3-4%	Negligible

More about the value chain of end-of-life management

System decommission → Collection → Recycling/reuse → End-market

Recycling

Disassembly (Frame, JB, cable) + **Delamination** (Glass, polymer) + **Material recovery** (Si, Ag, Cu, etc)

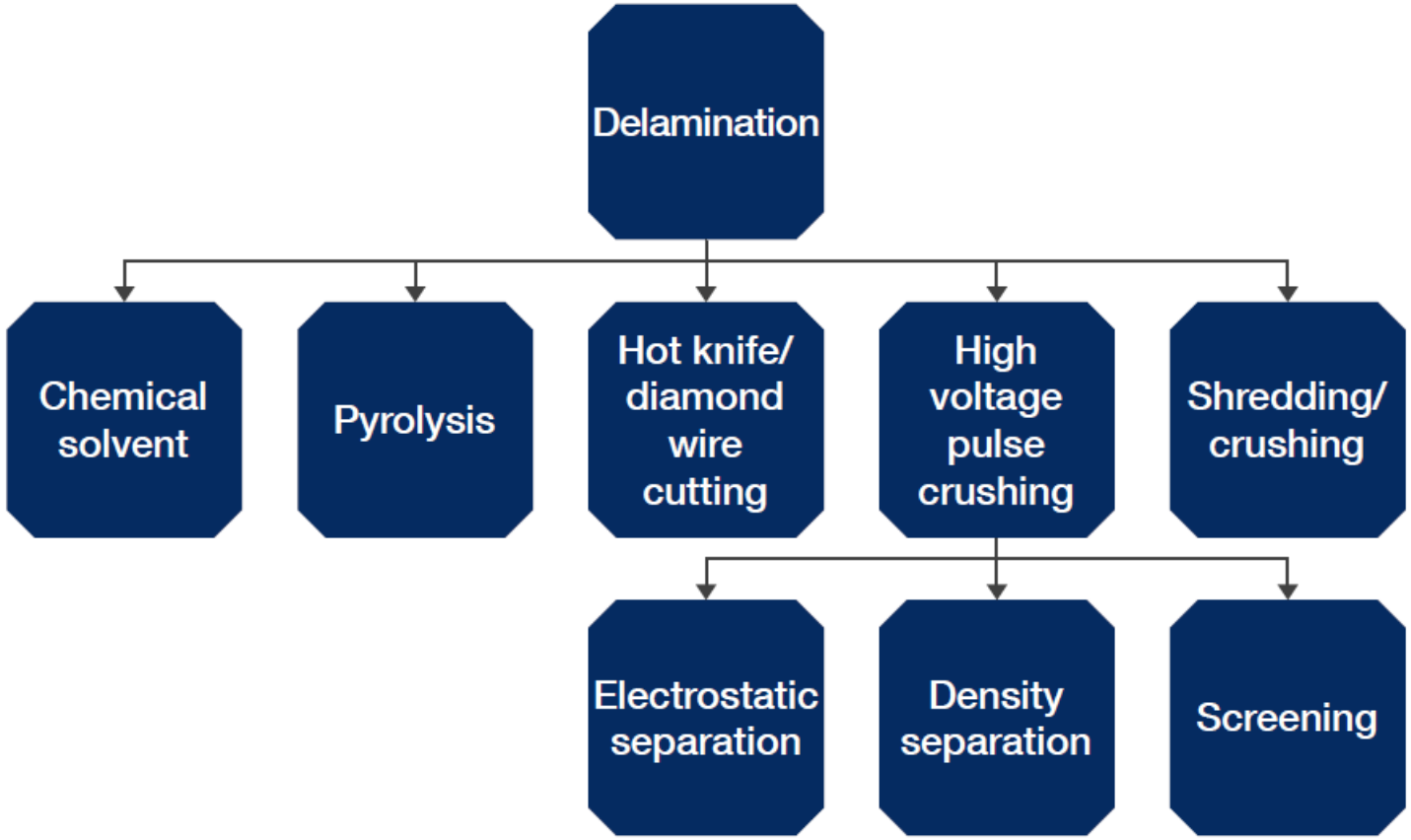
→ **Who will buy it?**

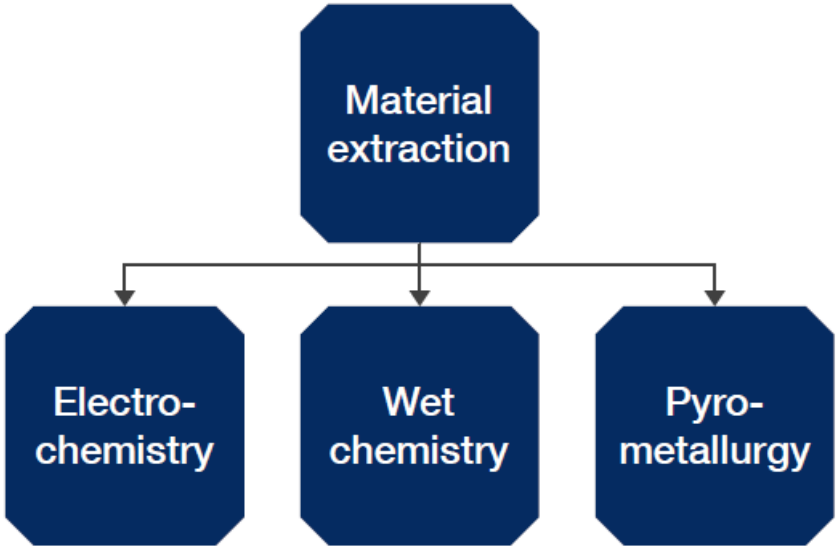
Reuse

Quality test (IV, PL, EL) + **Safety test** (current leakage)

How to recycle a panel?

Figure 18
Feasible silicon solar panel recycling technologies.





For recent advances at commercial/pre-commercial scale, check this out:
IEA PVPS Task 12 Advances in Photovoltaic Module Recycling (2024)

How can Australia implement these recycling technologies?

Two methods to implement PV recycling in Australia:

1) Bulk material recovery then send valuable fractions to existing material recovery facilities (MRF).
2) Dedicated P ble materials.

Cost-benefit analysis

Figure 22
Breakdown of annual cost structure for Option 1 electrostatic recycling at different operation capacity.

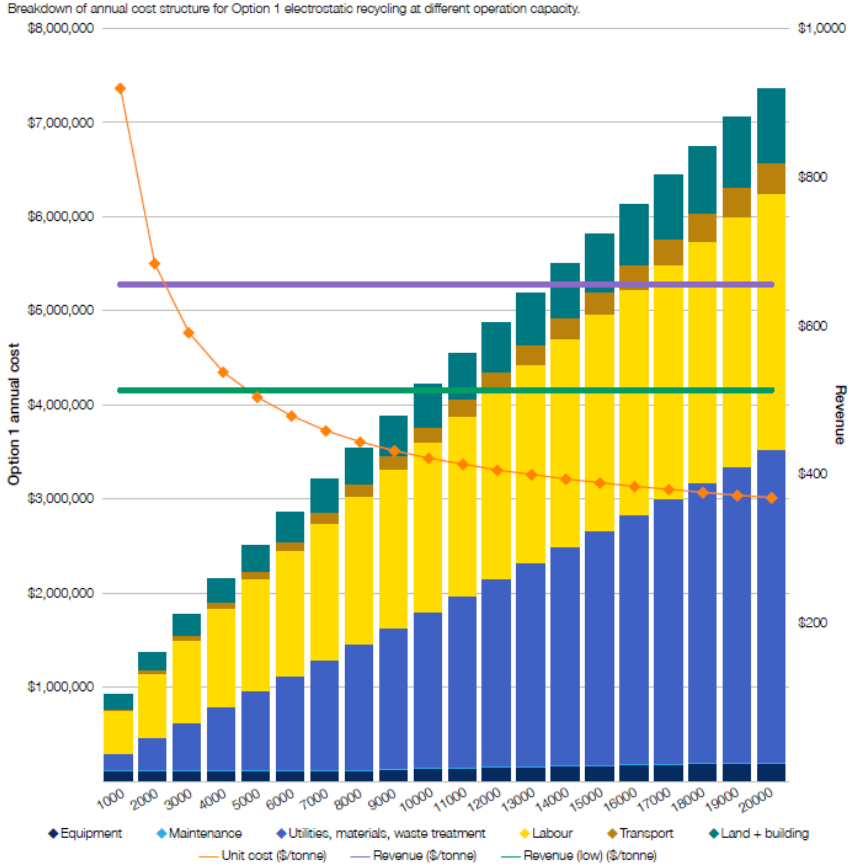
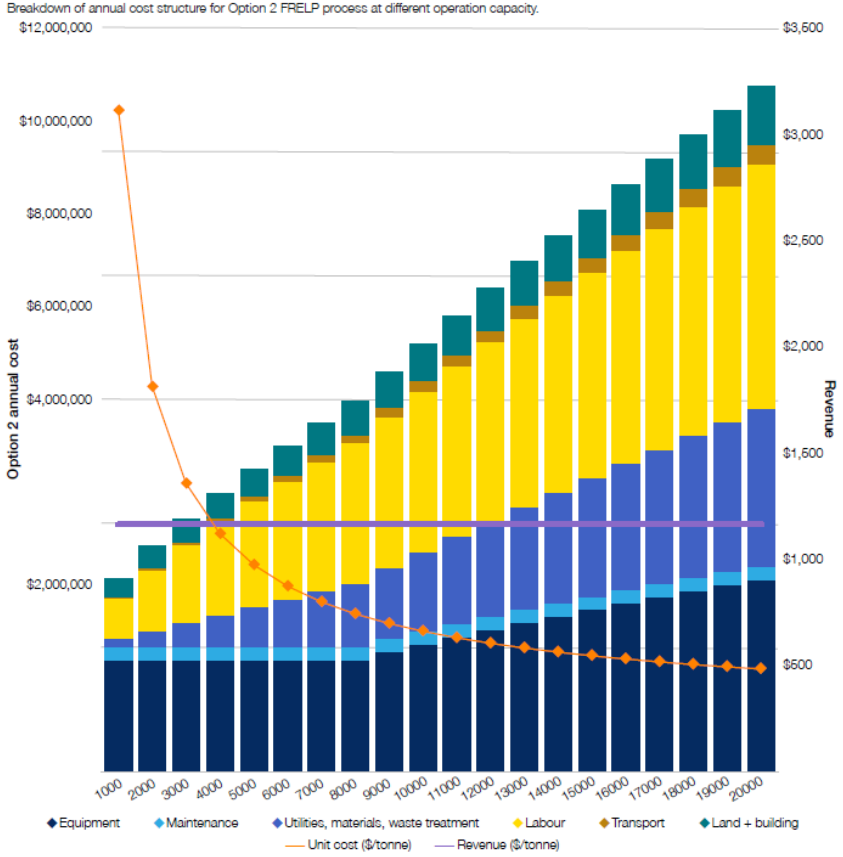


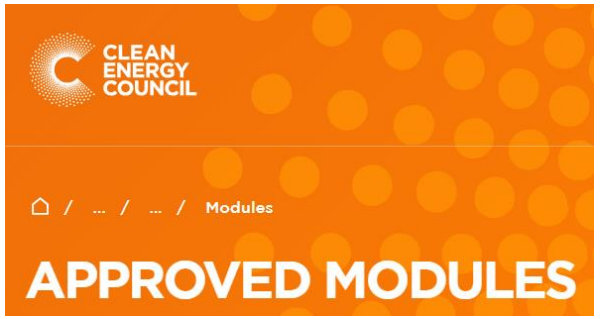
Figure 23
Breakdown of annual cost structure for Option 2 FRELP process at different operation capacity.



- Minimum viable scale: Option 1: 3,000 tonnes per year; Option 2: 5,000 tonnes per year.
- Current cost of recycling: $500 – 1000 per tonne, before accounting for the material revenue.
- **Current status in Australia: Option 1 only, missing a dedicated entity specializing in solar panel material recovery.**

How about reuse?

- Reuse is cheaper, at $3.5 to $9.5 per panel tested for reuse, but the market price for selling old panels is unknown.
- Although reuse is more desirable, second-life old panels pose safety concerns under the current AS/NZS 5033 solar standard, restricting their reuse in grid-connected systems.
- Old panels are not eligible to receive STCs.



Browse the Clean Energy Council's list of approved (fire-tested) solar photovoltaic (PV) modules suitable for installation under the Small-scale Renewable Energy Scheme (SRES).

4950 products from 110 manufacturers, showing manufacturers 1 - 15

56 **AE Solar GmbH**

MODEL NUMBER	ENHANCED LISTINGS	APPROVAL DATE	EXPIRY DATE
AE490CMD-120BDE (IEC 61215-2021)		01/02/2024	01/02/2027
AE475CMD-120BDE (IEC 61215-2021)		01/02/2024	01/02/2027
AE440CMD-108BDE (IEC 61215-2021)		01/02/2024	01/02/2027

The current end-market challenge

- There has been a constant challenge in finding a suitable end-market for recovered materials, especially glass, which constitutes 70% of the panel's weight. Current solutions involve repurposing the glass as a substitute for sand in concrete and bricks.
- The challenge extends beyond glass, as the highly mixed nature of components makes it hard to find markets for their use.
- Before being sold as second-hand products, panels should undergo safety and quality testing, and the resulting data should be available to buyers to establish trust. The absence of such testing criteria in Australia currently favours the adoption of new panels over second-hand ones.

CASE STUDY: Solar Panel End-of-life Recovery by Veolia

Veolia France - Rousset (Bouches du Rhône)

Veolia France worked with centralised eco-organisation Soren (ex-PV CYCLE France) to process and recover crystalline silicon as well as other components (aluminium, copper, glass…) from solar panels.

Strong focus on optimising the carbon footprint of the whole process on top of the recovery of materials: energy recovery, optimisation of logistics with the choice of location in the South of France.

- First in Europe.
- 5,000 tonnes per year capacity.
- 95% recovery rate.

Veolia Germany

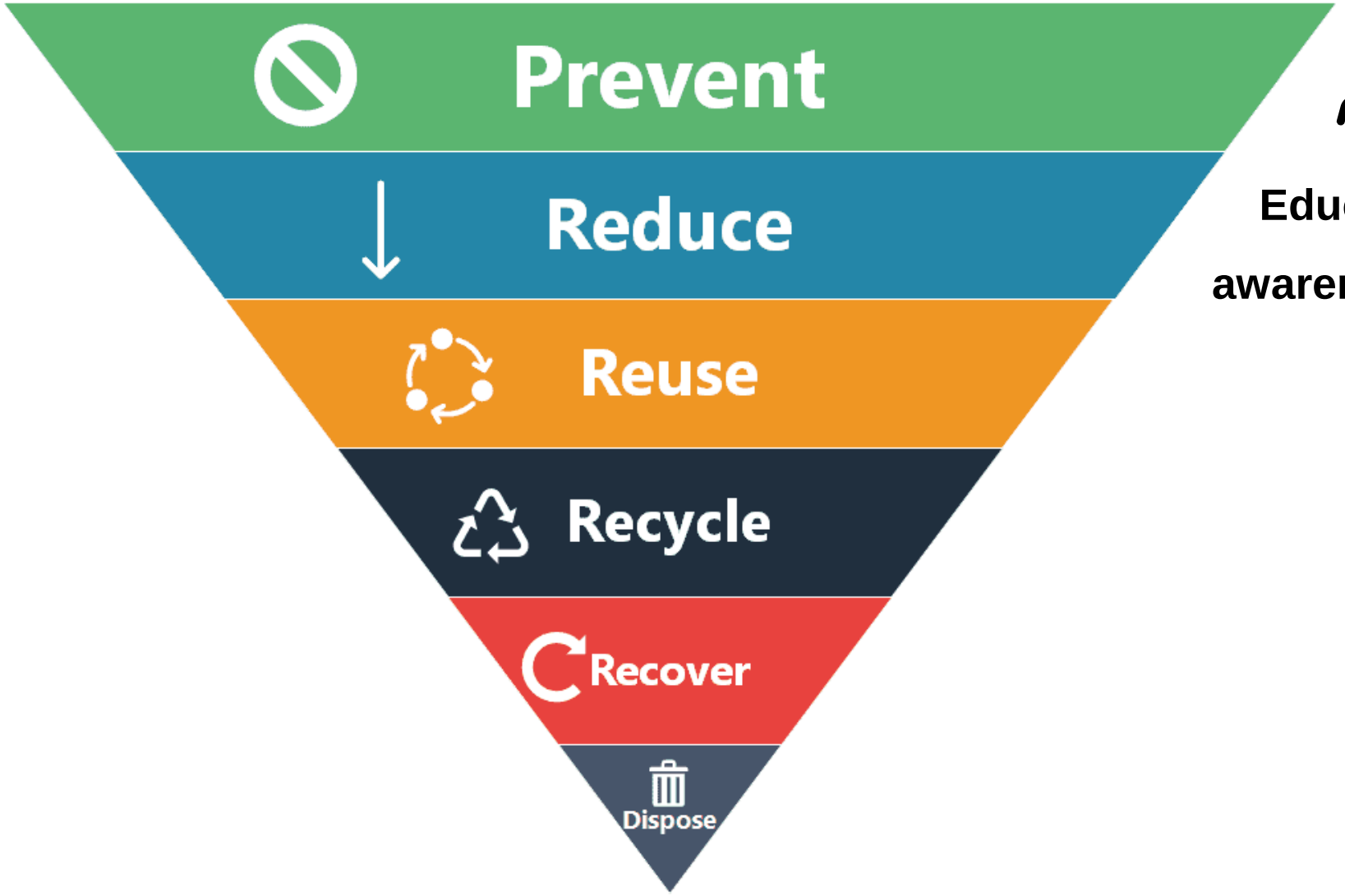
Veolia Germany developed a highly efficient and special process for the recycling of end-of-life photovoltaic (PV) modules - in final development stage.

Together with partner companies from the public and private sector operating along the PV module recycling chain, all PV module components are completely separated for the first time. This way, pure silicon, silver and glass, among other things, can be made available to the manufacturing industry again. Around 5,000 tonnes of disused PV modules are to be processed in the demonstration plant and the pilot will run until the end of January 2025.

Veolia has learned from experience the main conditions for PV recycling to be commercially viable are:

- National or *geography-based schemes* need to be in place to ensure *sufficient volume* for viable collection and processing to work financially.
- There should be *incentives* on recycling and recovery or restrictions on disposal to landfill.
- Understanding the variability in panel types in Australia, which will affect the process and *commodities management.*

What is the most cost-effective?



Education and awareness training

5. What is the regulatory landscape in Australia?

National Product Stewardship Scheme for Photovoltaic Systems has been listed on Minister's Priority List since 2016/17.

All end-of-life solar panels must be recycled or reused domestically:

- A national wide regulatory product stewardship for PV systems will be implemented by the end of 2025.
- An amendment to the Basel Convention will regulate the cross-border movement of solar panels, expected to come into effect in 2025.

This national scheme **mandates producers**, including manufacturers, importers, and all parties introducing solar panels to the Australian market**, to take responsibility** for the end-of-life management of these panels. Key aspects of the scheme include establishing recycling benchmarks, enforcing material traceability, and setting criteria for recyclers. **Financial responsibility for managing waste will transition from owners of small-scale systems to producers, while owners of large-scale PV systems (over 100kW) have the option to bear the end-of-life liability themselves.**

A Glance into PV Waste Management in France

- In France, the transposition of the WEEE Directive 2012/19/EU was made into French law in 2014 by the Décret n° 2014-928 of the French code of the environment.
- The only non-profit eco- organization so called Producer Responsibility Organization (PRO) approved by ministerial decree in France for the treatment of PV waste is **Soren** (formerly PV CYCLE France), which consequently has a monopoly on PV module waste management.
- Soren manages both collection and recycling by operating private tendering procedures that enable the centralization of PV waste management in France.
- Collection method: drop-off bins and on-site collection.

France

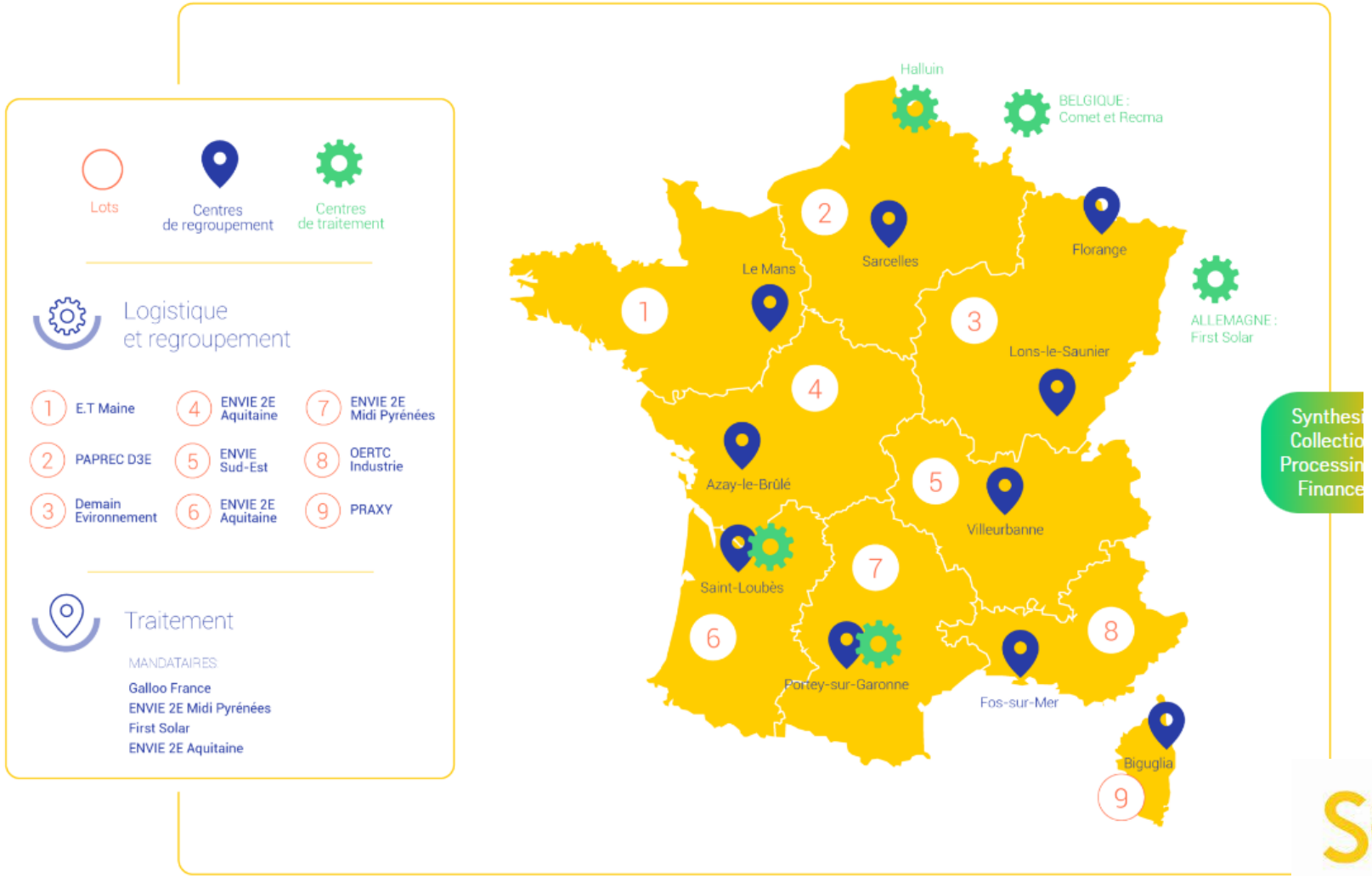
- According to the Environment Code, producers fulfills their obligations by collectively establishing approved eco-organizations. Producers include photovoltaic panel manufacturers, remote sellers, importers, introducers, third-party vendors, and resellers under its own brand, who places photovoltaic panels on the French market. Producers are responsible for governing these organization, transferring their obligations to them, and providing financial contributions in return.

PV.1 – Mono and polycrystalline (cSi) photovoltaic modules

By equipment	Module with aluminum frame		Aluminum frameless module	
weight range	Amount (excl. VAT)	Reference	Amount (excl. VAT)	Reference
Less than 1kg excluded	0.02€	PV.11101	0.03€	PV.11201
From 1 kg to 10 kg excluded	0.16€	PV.11102	0.28€	PV.11202
From 10 kg to 20 kg excluded	0,36€	PV.11103	0.63€	PV.11203
From 20 kg to 30 kg excluded	0.50€	PV.11104	0.87€	PV.11204
From 30 kg to 40 kg excluded	0.70€	PV.11105	1,22€	PV.11205
From 40 kg to 50 kg excluded	0.90€	PV.11106	1,57€	PV.11206
For each additional 10 kg started	*0.20€*		*0.35€*	

- As 1st Jan 2020.

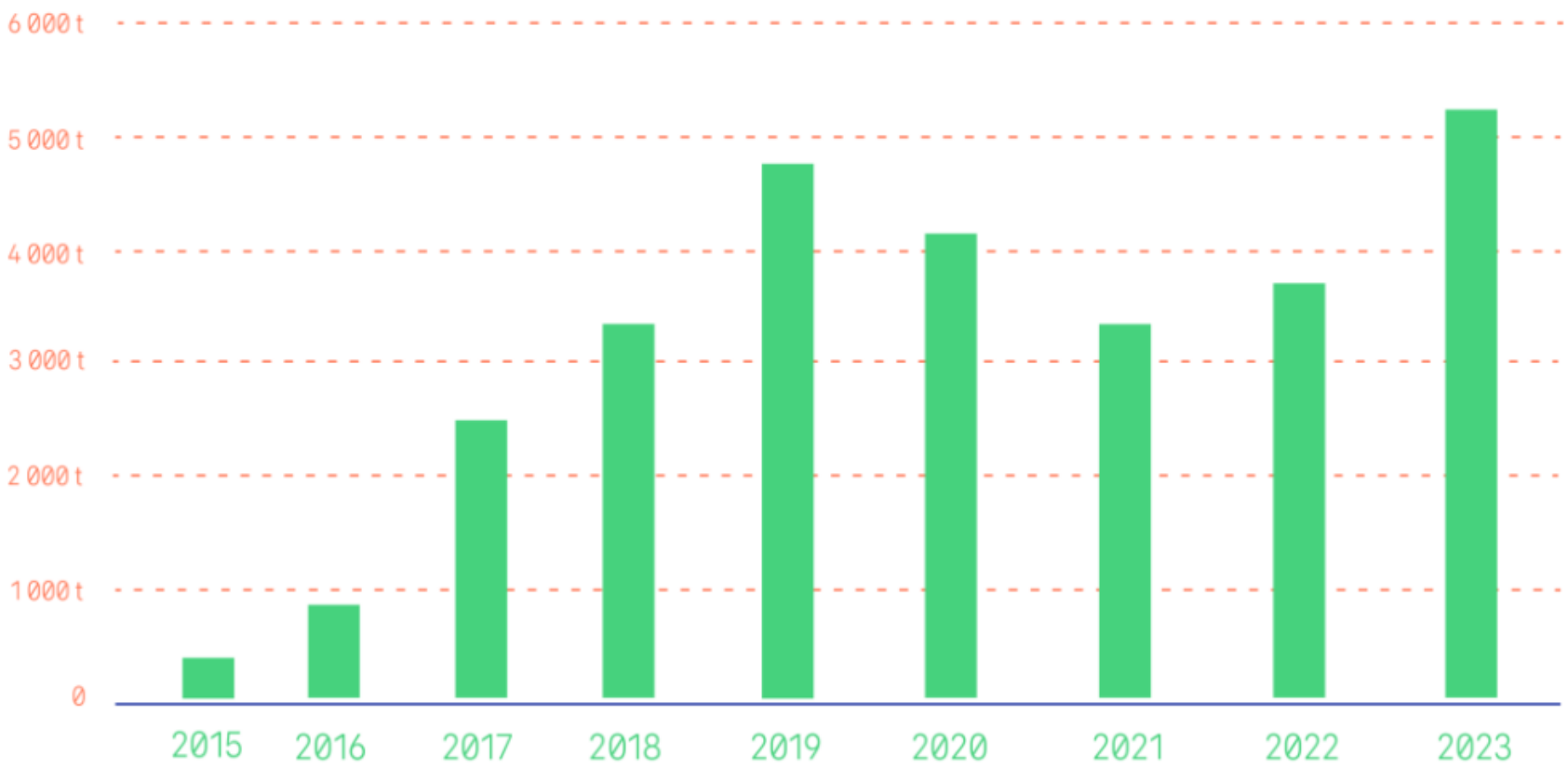
A glance into PV Recycling in France



A glance into PV Recycling in France

Evolution of the annual collection

of used photovoltaic panels in France in tonnes



A glance into PV Recycling in France

The grinding method:

1. *The reception and de-palletization of the panels on the processing center.*
2. *The pre-dismantling.*
3. *Grinding of laminates, screening and refining of fractions.*
4. *Air separation.*
5. *Densimetric or flotation separation.*
6. *Eddy current separation.*

Hot blade delamination *allows recycling with very high added value to recover as many components as possible from photovoltaic solar panels 🌞, in particular flat glass and strategic metals (silicon, silver and copper). A major innovation since it is a world first 🌎*

1. *Receiving and de-palletizing the panels at the processing center*
2. *The pre-dismantling.*
3. *Delamination process*
4. *Thermal process*
5. *Gentle chemical treatment*

https://www.soren.eco/re-traitement-panneaux-solaires-photovoltaiques/

PHOTORAMA

- PHOTORAMA is an EU funded innovation action striving to improve recycling of Photovoltaic (PV) panels and recovery of Raw Materials (RM), implemented by a consortium of 13 organisations.
- To develop trailblazing technologies to implement a strong and reliable PV recycling scheme.
- To demonstrate full circularity by re-injecting the secondary rare materials into cross sectoral value chains.
- Pilot line by 2024: 1200 ton/year.

What are the opportunities for addressing the emerging issue of EoL panels in Australia?

Lack of Large-Scale Technical Capability

Current barriers in Australia	Why do these barriers exist?	Recommendations to address barriers	How can these recommendations be implemented?
Lack of large-scale technical capability	Recycling aluminum frames and junction boxes are straightforward. Recycling glass, silicon, and silver is challenging due to lack of advanced technology Current methods involve manual removal and shredding, limiting high-purity recovery. Developing dedicated PV recycling technology remains ongoing in the country as current methods rely on e-waste standards.	Develop **technical capabilities** and equipment specifically for PV recycling	An efficient PV recycling approach yields over 95% recycling rates, recovering key materials for PV reuse rather than other sectors. Achieving this involves mechanical, chemical, thermal, or electrostatic separation. Supporting existing Australian PV recyclers and adopting global best practices can enhance material purity and recovery.

Lack of end-markets

Current barriers in Australia
Lack of end-markets

High recycling costs hinder adoption

Current barriers in Australia	Why do these barriers exist?	Recommendations to address barriers	How can these recommendations be implemented?
High cost	At present high recycling expenses hinder PV recycling. Consumers find landfilling cheaper than recycling (i.e., $2/panel to landfill compared to $10-20/panel to recycle). Recyclers face slim margins due to intricate technology, insufficient material returns to offset costs, especially when operating at a small scale.	Provide **government funding and grants into R&D / medium scale demonstration pilot**	Research into improving recycling processes and recovering materials at a higher purity is critical, so they are suitable to be re-used. For example, UNSW achieved 99% solar cell separation, while Deakin University has developed a highly valuable chemical-free nano silicon extraction. Commercializing, scaling, and government support is becoming more essential. Growing PV recycling demand boosts recyclers' profits, and subsidies could encourage consumer participation.

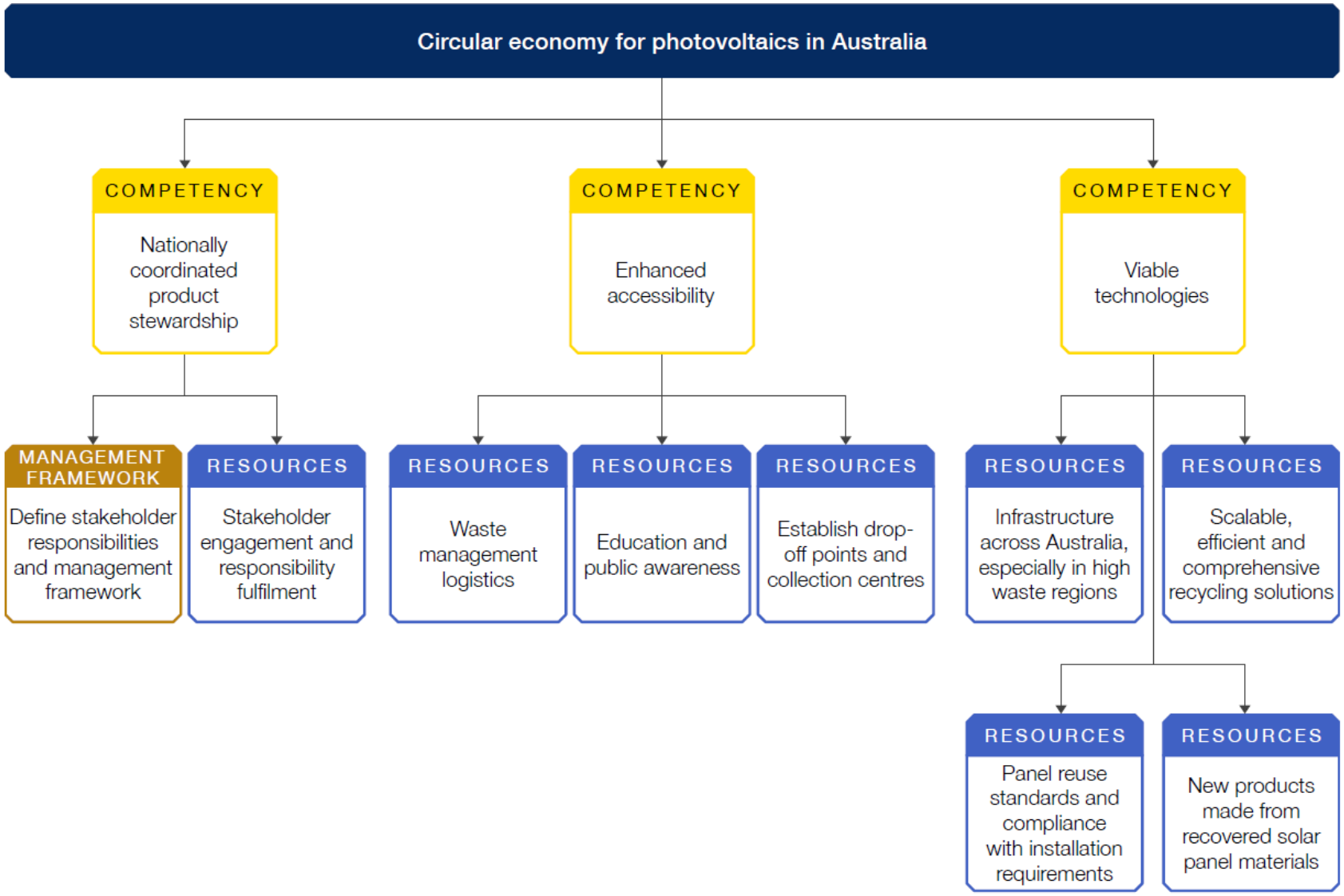
Lack of enforcement

Current barriers in Australia	Why do these barriers exist?	Recommendations to address barriers	How can these recommendations be implemented?
Lack of enforcement	Currently, PV recycling is not mandated on a federal level, and only Victoria has banned PV panels from being landfilled. There are little incentives for both consumers and PV recyclers, and the environmental consequences of the growing PV waste problem are not reflected in the government's current regulations.	**Mandate recycling** and place more responsibility on manufacturers	It is essential to establish a product stewardship program for federal recycling mandates or higher landfilling penalizations for PV panels. Following Europe's success, manufacturers should bear responsibility for end-of-life collection and recycling of their products. This might raise initial costs but offers an efficient way to handle PV waste.

Logistical challenges

Current barriers in Australia	Why do these barriers exist?	Recommendations to address barriers	How can these recommendations be implemented?
Logistical challenges	Given the size of Australia, it is a challenge to coordinate PV recycling at a nationwide scale. This includes utility scale solar farms in regional and remote areas. Coordinating collection points and recycling facilities to take into account the widespread distribution of panels across the country will be a significant barrier.	Develop a **streamlined network between manufacturers, consumers and recyclers**	Strategies regarding logistics could be addressed through the proposed product stewardship scheme that is currently under consultation. It would be beneficial to set up dedicated disposal/collection sites across the country to account for recycling of rooftop solar panels. For regional and remote solar farms, system owners should create a decommissioning plan, which factors in the most efficient way to recycle decommissioned panels in bulk. Additionally, placing some responsibility with local manufacturers (if established) could help to coordinate a streamlined process.

Industry roadmap: Actions to foster a circular economy for the photovoltaic industry in Australia over the next 12 years



Industry roadmap

Actions to foster a circular economy for the PV industry in Australia over the next 12 years

No	Action	Who	Timeframe
1	The national product stewardship scheme should define management structures and stakeholder responsibilities, ensuring clarity and accountability throughout the industry.	DEECCW	**Within the next 2 years**
2	Engage in the national product stewardship scheme and ensure responsibilities are met throughout the industry.	All stakeholders.	**2-5 years**

Regulatory Measures: Enact a nationwide product stewardship program to fund and oversee the management of PV end-of-life to support early-stage industry development.

Industry roadmap

Actions to foster a circular economy for the PV industry in Australia over the next 12 years

No	Action	Who	Timeframe
3	Awareness training. Design and distribute educational materials to raise awareness on PV sustainability issues and end-of-life options for solar panels for consumers, installers, and industry stakeholders.	Local councils, governments, and environmental agencies, Home Solar Providers	**Within the next 2 years**
4	Initiate national-wide drop-off points and collection centres in high solar panel waste regions (pending on the outcome of product stewardship)	Local councils, governments, and environmental agencies	**2-5 years**
5	Optimise waste logistics by creating a streamlined network to transport waste efficiently and develop a comprehensive waste tracking and monitoring system	Waste management companies & logistic providers	**5-10 years**

Collection Accessibility: Create easily accessible drop-off points, and increase public awareness about PV waste management.

Industry roadmap

Actions to foster a circular economy for the PV industry in Australia over the next 12 years

No	Action	Who	Timeframe
6	Invest in and develop full-recycling technologies tailored to Australia's recycling needs.	Research institutes, tech developers & PV industry stakeholders	**Ongoing**
7	Drive the circular economy by innovating products from recycled PV materials and explore revenue streams in other circular economy interventions such as reuse and repair.	PV manufacturers, research institutes, circular economy innovators, solar panel recycling company	**Ongoing**
8	Develop panel reuse standards. The photovoltaic industry should lead developing panel reuse standards and ensure the standards comply with current PV system installation requirements in Australia.	PV industry consortiums, standard regulatory body, CEC	**Within the next 3 years**

Technological Advancement: Promote innovation in scalable, efficient, and comprehensive recycling technologies and develop robust reuse standards and procedures to enable a PV circular economy.

Industry roadmap

Actions to foster a circular economy for the PV industry in Australia over the next 12 years

No	Action	Who	Timeframe
9	Establish large-scale (approx. 5000 tonnes/year) PV waste treatment facility in Brisbane, Sydney, Melbourne, Adelaide, Perth.	Solar panel recycling company with the support from governments, EPAs and product stewardship scheme	**Within the next 3 years**
10	Establish a few medium scale PV waste management facilities in regional Australia.	Solar panel recycling company with the support from local councils / governments, EPAs and product stewardship scheme	**5-10 years**

Facility Development: Establish large scale PV waste management facilities (over 5,000 tons/year) in five big cities within three years and expand to regional areas within six years.

Key recommendations

The analysis highlights Australia's potential to develop solar panel recycling and reuse market within 12 years through strategic initiatives. Key recommendations include:

- **Regulatory Measures**: Enact a nationwide product stewardship program to fund and oversee the management of PV end-of-life to support early-stage industry development.
- **Collection Accessibility**: Create easily accessible drop-off points, and increase public awareness about PV waste management.
- **Technological Advancement**: Promote innovation in scalable, efficient, and comprehensive recycling technologies and develop robust reuse standards and procedures to enable a PV circular economy.
- **Facility Development**: Establish large scale PV waste management facilities (over 5,000 tons/year) in five big cities within three years and expand to regional areas within six years.

SOLA 5051 – 2024 T2 Life Cycle Assessment

Week 8 LCA of Renewable Energy Systems

K-H13-G001 - H13 Lawrence Theatre

Tuesday 16th July 9 – 11am

Convenor: Rong Deng (rong.deng@unsw.edu.au)

Questions?

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