Funded by the European Union

This activity is part of the European Union Climate Dialogues (EUCDs) project

AUS02 PV Circularity
Policy Recommendations Report

Overview Report

Authors:

Brett Hallam (ITP Renewables)

Drew Thompson (ITP Renewables)

Rong Deng (UNSW Sydney)

ENGINEERING | STRATEGY & ADVISORY | ANALYTICS

OVERVIEW

Australia has rapidly adopted solar photovoltaics (PV) over the last several years, bolstered by feed-in-tariffs and government subsidies. By the end of 2023, Australia exceeded 34 gigawatts of installed PV capacity, making the country a world leader for solar per capita.

Today, more than 60% of solar PV in Australia is made up of small-scale PV systems with a capacity below 100 kWp, which are predominantly installed on residential and commercial rooftops.[1,2] However, this growth of PV will result in a similar increase in PV waste, with Australia forecast to exceed 50,000 tonnes of annual PV waste by 2025. By 2035, that will increase to over 90,000 tonnes per year (see Figure 1 below).

While Australia is a clear leader in the deployment of rooftop solar, it is lagging in its efforts to establish a system of PV circularity. The growth of PV waste in Australia is accelerated by panels commonly entering the waste stream well before they reach the end of their design life of 25-30 years. A recent analysis highlighted that the average PV panel lifetime in Australia may instead be just 15-20 years, with rooftop solar systems particularly susceptible to shorter operational lifetimes.[3]

Solar panels commonly contain materials that are both energy- and emissions- intensive to produce, such as aluminium and silicon, as well as critical and valuable materials required for the clean energy transition like silver and copper. They often also contain toxic materials like lead and antimony, while 5% of panels contain cadmium (thin-film solar panels).

Without action, much of Australia's PV waste Figure 1 will enter landfill, resulting in a loss of valuable resources, and presenting both environmental and health hazards. To prevent this, this report outlines clear paths to improving the handling of PV waste in Australia.

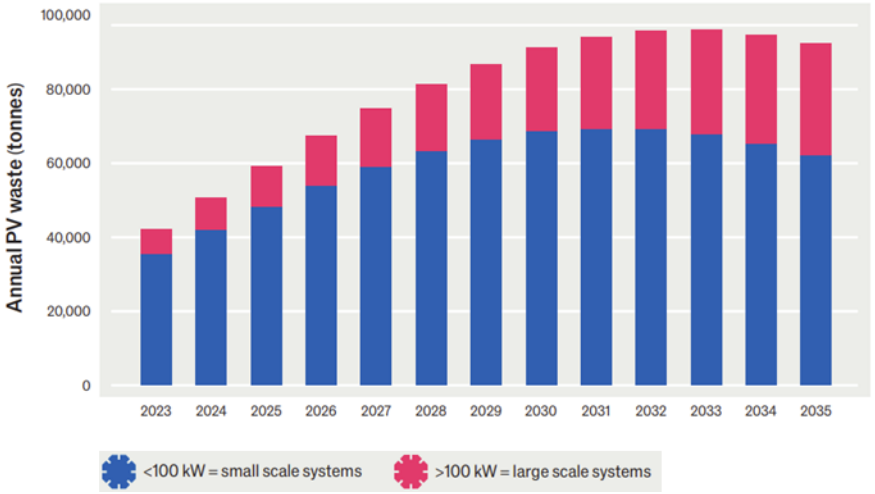

Figure 1: Annual Australian PV Waste Projection. Data sourced from: "Scoping Study: Solar Panel End-of-life Management in Australia", ACAP, March 2024

[1] Australian PV Market since April 2001, Australian PV Institute, 2023
[2] Carroll D., Australia's cumulative installed PV capacity tops 29.7 GW., 2023
[3] Tan V. et al. (2022). "Estimating the Lifetime of Solar Photovoltaic Panels in Australia". Sustainability 14, 5336. https://doi.org/10.3390/su14095336

A Circular Economy for Solar Panels

To address solar panel waste accumulation, Australia should seek to facilitate a circular economy for PV (see Figure 2). The circular economy framework presents strategies to reduce waste, mitigate environmental impacts, and maximise the recovery and reuse of resources. Due to Australia's reliance on imported PV modules, there is limited potential for policy to enact early-stage circularity strategies that would influence the module design and manufacturing of these panels. Therefore, circularity strategies should aim to extend the life of solar panels, through actions such as reuse and repair, and to minimise waste creation through recycling.

The current landscape for solar panel reuse, repair, and recycling in Australia is detailed below, followed by policy options and actions to support PV circularity in Australia.

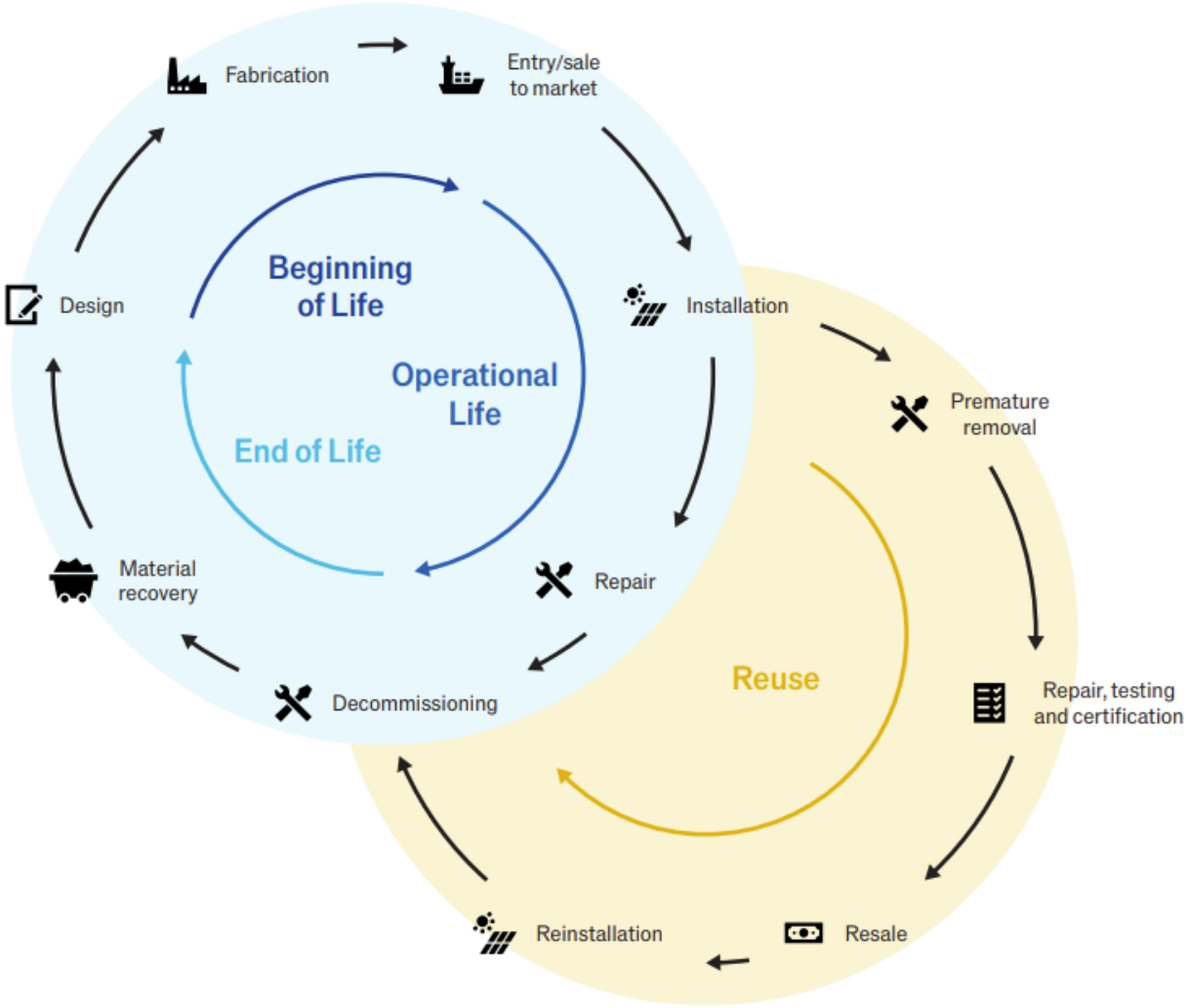

Figure 2: Indicative circular economy framework for solar panels

Solar Panel Reuse

PV reuse currently occurs in niche markets in Australia, typically off-grid applications such as community solar farms, bore pumps, hobby farms, and caravans. Stakeholders also identified instances where decommissioned PV modules from Australia, Europe, and North America were exported to markets in developing countries, which presents a risk of waste relocation. In Australia, uncertainty surrounding the compliance of second-life panels can limit their uptake by consumers. Further, the low cost of new panels, coupled with Small-scale Technology Certificate rebates, impedes the price competitiveness of second-life panels, inhibiting PV reuse markets in Australia.

Solar Panel Repair

PV repair can address some panel faults and damage. However, PV repair opportunities are limited as panels are designed to remain sealed in harsh environmental conditions for 25-30 years. As such, damaged, degraded, or faulty modules often require removal or replacement. In such cases, system owners and installers often seek to replace an entire system, resulting in functional panels unnecessarily entering the waste stream.

Solar Panel Recycling

PV recycling can reduce the environmental impact and health risks from toxic materials and avoid the potential leaching of these materials into groundwater. While PV recycling operations in Australia are gradually developing, most companies are in the preparation or development phase, with only a few capable of large-scale operations.

Challenges to PV circularity in Australia

PV circularity in Australia faces several challenges, including:

- **Landfill** as a cheap and convenient option for PV module disposal at end-of-life for much of Australia.
- **Material recovery** technological challenges due to the complexity of PV modules and variations in module characteristics.
- **Logistics costs** due to the high dispersion of small-scale rooftop PV installations in Australia, and remoteness of many Australian communities.
- **Challenging business case** arising from difficulties establishing economies of scale in the short term, and lack of end markets due to a lack of PV manufacturing in Australia.
- **Generous government subsidies** such as the Small-scale Technology Certificate (STC) scheme, which entices consumers to prematurely replace functioning PV systems.

EIGHT KEY ACTION AREAS TO IMPROVE PV CIRCULARITY

The EUCDs engaged ITP Renewables and UNSW to conduct five hybrid policy dialogue workshops on solar PV circularity, engaging over 140 individuals across Australia, Europe, China, India, and USA. Attendance was diverse and spanned academic organisations, consultancies, government agencies, industry bodies, PV manufacturers, quality testing laboratories, recycling and waste management companies, retailers, and solar developers.

Drawing on insights from these workshops, ITP Renewables and UNSW identified eight key action areas for developing government policy and support measures, as highlighted in Figure 3.

All eight action areas are detailed further in the subsequent sections of this overview report.

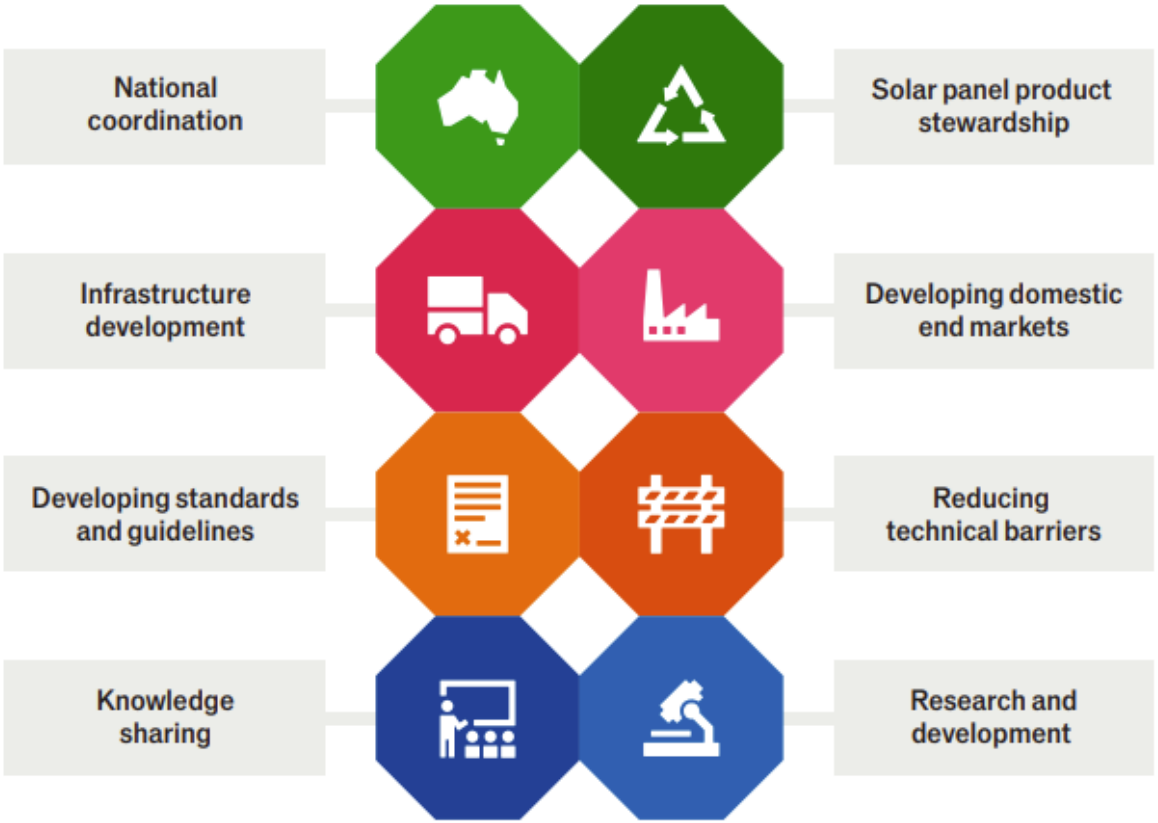

Figure 3: Key action areas to improve PV circularity in Australia

ACTION 1: NATIONAL COORDINATION ON PV WASTE MANAGEMENT POLICY

Efforts for managing PV waste in Australia must be co-ordinated nationally to ensure consistency across states and territories. Pathways to facilitate national coordination on PV waste management policy are outlined below.

1.1: National Taskforce on PV Waste Management

National co-ordination of PV waste management in Australia can be realised through the **establishment of a National PV Waste Management Taskforce under the Department of Climate Change, Energy, the Environment and Water**. The taskforce should include members from state government departments managing waste, local councils, and industry bodies.

The taskforce should oversee efforts to remove barriers to PV waste management in Australia and promote circularity through policy, education, and establishing PV waste management capabilities. The taskforce could also include opportunities for Australia to assist in the management of PV waste in our neighbouring Pacific Island nations.

1.2: Developing a National PV Waste Action Plan

A **National PV Waste Action Plan would detail the steps and actions required to manage PV waste** in Australia and improve PV circularity by addressing key challenges such as those identified above.

The National PV Waste Action Plan should be developed by the PV Waste Management Taskforce in consultation with key stakeholders. Upon completion, findings should be incorporated into Australia's overarching National Waste Policy and National Waste Policy Action Plan.[4]

1.3: Harmonised State Landfill Bans on PV Waste

Landfill bans should be implemented consistently across Australian states and territories, to redirect PV waste towards circular management pathways and to support recyclers in building inventory and establishing economies of scale. This should also include **bans on the landfill of PV laminate stacks** (see Figure 4), to prevent the laminate stack going to landfill as 'residual waste'.

However, landfill bans are a blunt instrument and may not be as effective in achieving other outcomes like high rates of recycling and material recovery. As such, **landfill bans must be complemented by supportive policies and actions to reduce other barriers to PV reuse and recycling.**

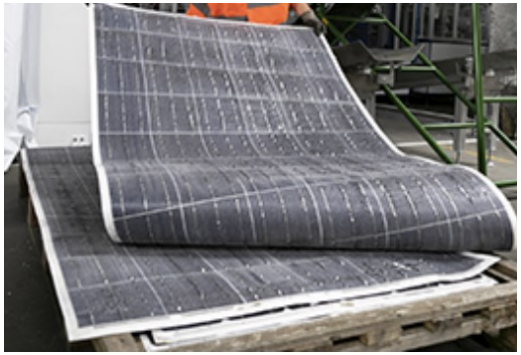

Figure 4: PV laminate stack left over after removal of junction box, aluminium frame, and glass

[4] National Waste Policy Action Plan 2019, Department of Climate Change, Energy, the Environment, and Water, 2019

ACTION 2: PV PRODUCT STEWARDSHIP

In October 2022, the Australian Government announced plans to develop a national product stewardship scheme for solar PV systems and household electronics, expected to commence in 2025. PV collection and recycling will be funded by liable parties (producers or importers) through fees paid to the scheme administrator once PV panels are placed on the market. The Project Team welcomes the establishment of product stewardship for PV in Australia, as it will support the development of waste collection networks, improve the financial certainty for PV recyclers, and increase transparency for PV waste management.

Figure 5: PV panels in a solar farm

2.1: Enable voluntary partnerships

The proposed scheme should include options for liable parties to establish **voluntary partnerships with PV recyclers** to fulfill their regulatory obligations under the scheme, such as for solar farms (see Figure 5). This will support innovation by incentivising PV recyclers to pursue competitive advantages such as low pricing, high efficiency, high recovery rates and the recovery of valuable materials.

2.2: Incentivising high-value material recovery

The scheme should incentivise high-value recovery of solar panels to achieve an outcome of over **80% material recovery**, in alignment with the National Waste Policy. However, as this value can readily be achieved from a PV panel's aluminium frames and glass alone, additional financial incentives could be used to encourage the recovery of valuable materials such as silver and silicon.

80% material recovery can be achieved from the module glass and aluminium alone. We need to make sure valuable materials like silver, copper

2.3: Tracking recovered materials

Stakeholder reporting obligations should seek to **align with the National Framework for Recycled Content Traceability**, where possible. Target areas within the scope of the framework include the quantity, composition, and quality of materials recovered.

ACTION 3: DEVELOPMENT OF PV COLLECTION, RECYCLING, AND TESTING INFRASTRUCTURE

The size and geographic distribution of solar panels across Australia presents logistical challenges for PV circularity. To support PV product stewardship, **the development of PV collection, recycling, and testing infrastructure** across Australia will be needed to reduce logistic costs and ensure equitable access to collection services.

3.1: Collection Infrastructure

Collection points will need to be distributed throughout Australia to ensure equitable access to collection services. These could be co-located with local council waste management facilities, as with the National Television and Computer Recycling Scheme. In addition, drop-off points could be established at PV retailers, allowing a 'reverse logistics' model where installers can return PV waste when they acquire new stock.

3.2: Recycling Infrastructure

Centralised recycling facilities will be required to establish economies of scale for material recovery from end-of-life PV panels. Target areas for developing recycling infrastructure in Australia include the greater Sydney, Melbourne, Brisbane, Adelaide and Perth regions, which will account for over 70% of expected waste by 2030. Following this, additional facilities could be established in large regional centres (see Figure 6). [5]

70% of Australian PV waste by 2030 will originate from within 150km of the 5 largest Australian cities

3.3: Testing Infrastructure

After collection, **testing facilities are required to ensure the functionality, safety, and performance of second-life panels**. Testing facilities could be collocated with recycling facilities to capitalise on collection networks.

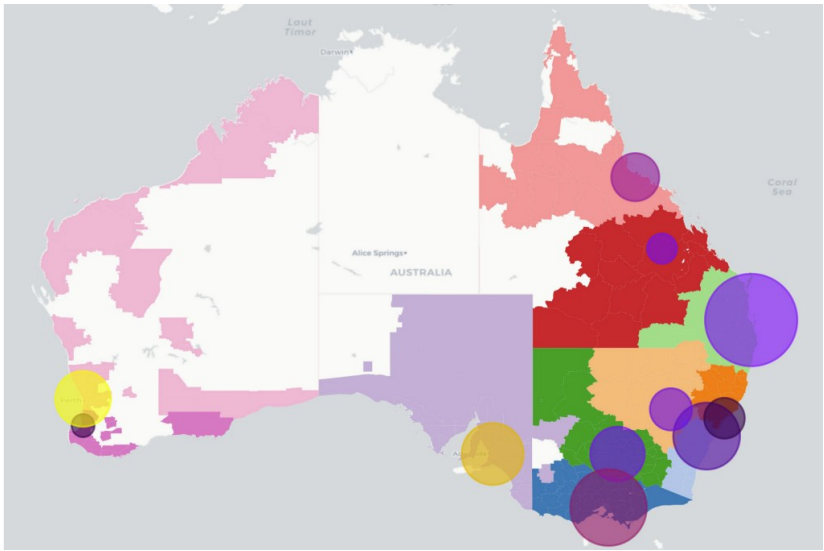

Figure 6: Optimal locations for large-scale PV recycling facilities in Australia. Source: "Scoping Study: Solar Panel End-of-Life Management in Australia", ACAP, March 2024

[5] "Scoping Study: Solar Panel End-of-life Management in Australia", ACAP, March 2024

ACTION 4: DEVELOPMENT OF END MARKETS FOR RECOVERED MATERIALS

With less than 50 MW of annual PV module production in Australia, a key challenge facing PV recyclers is a lack of end-markets for recovered materials. **Developing end markets for recovered PV materials will be essential** to support the business case for PV recycling. Further, end markets for PV materials will provide an additional incentive for recyclers to pursue high recovery rates.

4.1: International partnerships

Given limited local manufacturing, Australia could seek to **connect PV recyclers with countries with existing PV manufacturing** capacity such as Europe, the US, India, China, and South-East Asia for the export of recovered materials. This will enable recovered materials to return to the PV supply chain for improved circularity in the short-term.

4.2: Establishing local PV module manufacturing

Local PV manufacturing, such as the establishment of local module assembly, solar glass and module frame manufacturing under the Australian Renewable Energy Agency's Solar Sunshot program,[6] could provide a pathway to return recovered materials such as glass cullet (Figure 7) to the domestic PV supply chain. The current volume of PV waste in Australia (50,000 tons per year), contains sufficient glass and aluminium to manufacture 1 GW of solar panels per year, which is 20% of Australia's current demand.

Australia's current volume of 50,000 tons of PV panel waste is sufficient to meet 20% of the nation's demand for solar

4.3: Incentivise manufacturing with recovered materials

Bonus production credits could be provided under the Solar Sunshot program for manufacturing PV modules or components with recovered materials from end-of-life PV. This will provide a financial incentive for PV manufacturers to improve the circularity of their products and increase demand for recovered materials.

Figure 7: Recovered glass cullet from PV panels

[6] https://arena.gov.au/funding/solar-sunshot/

ACTION 5: DEVELOPMENT OF STANDARDS AND GUIDELINES FOR SECOND-LIFE AND END-OF-LIFE PV

Australia should seek to develop **nationally consistent standards and guidelines** on the management of PV reuse, repair and recycling. This should also consider guidance for the control of exporting second-life PV products.

5.1: Guidelines and standards for installers

For installers, **guidelines for decommissioning, handling, and transport** of used PV systems are important to minimise the number of broken and poorly packaged panels entering facilities for reuse and recycling (see Figure 8).

5.2: Guidelines and standards for recyclers

For recyclers, **standards and/or guidelines regarding the storage and processing** of panels should be implemented to address risks including leaching of toxic materials, toxic gases from thermal processes, the use of hazardous chemicals, and respiratory risks associated with crushing solar panels. Of particular concern are fine glass and silicon powders which may cause respiratory problems, including silicosis.

5.3: Guidelines and standards for second-life testing

For PV testing facilities, **standards and guidelines should detail testing procedure**s for second-life PV panels to ensure the quality and safety of products entering the second-life market. At a minimum, testing procedures should include visual inspection, electroluminescence or photoluminescence tests, and power tests.

5.4: Regulating exports of solar panels

To prevent the relocation of PV waste to overseas markets under the guise of reuse, Australia should develop **standards governing the export of used PV** in line with technical guidelines for the transboundary movements of used electrical and electronic equipment under the Basel Convention. These guidelines include the following requirements:

- A contract stating the panels are for direct reuse and are fully functional.
- Evidence of product testing.
- A declaration that none of the panels are waste according to the Basel Convention.
- Protection against damage during transport, loading, and unloading.

Figure 8: A broken solar panel at a PV recycling facility

ACTION 6: REMOVAL OF TECHNICAL BARRIERS TO STREAMLINE PV RECYCLING ACTIVITIES

Workshop stakeholders consistently noted that the large variation in solar panels on the market (see Figure 9) coupled with the uncertainty around the material composition of these panels creates challenges for PV circularity. Policy actions could seek to streamline PV recycling processes (like panel characterisation and batch processing) through more uniform panel production standards and increased product transparency.

6.1: Panel standardisation

Panel standardisation could reduce module variation in the market, reducing barriers to repair, reuse, and recycling. Given Australia's small market, implementing panel standardisation should involve partnerships with larger markets such as the US and Europe, or global initiatives such as the International Energy Agency's Photovoltaic Power Systems program.

With over 105,000 PV panel variations to deal with, a consistent challenge identified by PV recyclers is the overwhelming diversity of PV panels over the years

6.2: PV panel labelling

Additionally, Australia can mandate comprehensive and robust **PV panel labelling** detailing panel content, performance, and handling requirements, akin to the European Union's forthcoming Ecodesign labelling. This provides transparency, which can allow consumers to make sustainable purchase decisions. Further, it can communicate repair options to installers, while also streamlining panel characterisation for re-use, recycling, and tracking of material recovery rates.

Figure 9: Different module types at a PV recycling facility

ACTION 7: LOCAL KNOWLEDGE BUILDING

To support all previously detailed actions to improve PV circularity in Australia, education and training is required to build local knowledge – both for training the workforce, and to prevent the premature retirement of PV systems, which will help to reduce waste.

7.1: Training the PV recycling workforce

Establishing widespread PV recycling in Australia could see up to 350 local jobs at recycling facilities.[7] **Training programs** should be developed for the future PV recycling workforce (see Figure 10), potentially by leveraging expertise in countries with an established PV recycling industry, such as EU Member States.

Widespread PV recycling in Australia could create up to 350 local jobs at recycling facilities

Source: "Scoping Study: Solar Panel End-of-life Management in Australia", ACAP, March 2024

7.2: Education to prevent early PV retirement

Education for consumers and installers can work to build awareness about PV panels, their expected lifetimes, PV recycling, and to **reduce premature retirement of functioning PV systems**. This could include building consumer awareness on how long PV systems are expected to work for, and whether their PV systems are working effectively.

"I regularly get calls from friends asking for advice when installers have recommended that they take off working PV systems to upgrade to the latest technology".

Dr Muriel Watt AM – Analyst for ITP Renewables and the APVI

Figure 10: Workers in a PV recycling facility

[7] "Scoping Study: Solar Panel End-of-life Management in Australia", ACAP, March 2024

ACTION 8: RESEARCH AND DEVELOPMENT

Research and development are both required to improve PV circularity in the first six action areas. Key areas for research and development include finding suitable end markets for recovered materials (Figure 11) and developing commercial PV recycling technology.

8.1: Developing end markets

Funding research and development for end markets for materials recovered from waste PV will be beneficial for unlocking offtake options and stimulating demand, which will improve the business case for PV recycling. Research could also investigate the commercial viability of using recovered materials in manufacturing or other industrial processes, targeting the use of silicon and glass.

8.2: Developing commercial PV recycling technology

Research and development could investigate **developing 'good practice' commercial recycling processes** targeting the recovery of high-quality materials for use in the PV supply chain and other industries

Figure 11: Crushed PV panel materials. Sourced from "Scoping Study: Solar Panel End-of-Life Management in Australia", ACAP, March 2024

Funded by the European Union

This activity is part of the European Union Climate Dialogues (EUCDs) project

A TIMELINE FOR IMPROVING PV CIRCULARITY IN AUSTRALIA

An indicative timeline of actions to improve PV circularity in Australia is shown below.

Action	Responsible stakeholders	Timeline
National co-ordination of PV waste management by establishing a National PV Waste Management Taskforce	Department of Climate Change, Energy, the Environment and Water (DCCEEW) with input from state and territory governments	2024
Development of a National PV Waste Action Plan to be incorporated into the National Waste Policy and National Waste Policy Action Plan	DCCEEW, state/territory governments, local councils, solar industry stakeholders, Taskforce on Consumer Energy Resources	2025
Implement harmonised state-wide landfill bans on sending PV waste across Australia for both PV panels and PV laminate stacks, establish logistics and collection centres across Australia, enabling 'reverse logistics' where possible.	DCCEEW, state and territory governments, local councils	2025
Implement the e-stewardship program for PV recycling with incentives to achieve a minimum 80% material recovery outcome. Ensure a pathway for liable entities to establish direct partnerships with PV recyclers to meet their obligations. Adopt the National Framework on Recycled Content Traceability and incentivise high-value material recovery.	DCCEEW, state and territory governments	2025
Establish good-practice PV recycling and testing capability near major Australian cities with large volumes of end-of-life PV panels	DCCEEW, state and territory governments, PV recyclers	2025
Establish PV panel and solar glass manufacturing in Australia under the Australian Renewable Energy Agency's SunShot Program, with bonus production credits for manufacturing PV materials from recovered end-of-life PV panels.	DCCEEW, Australian Renewable Energy Agency, state and territory governments	2026
Develop new standards for decommissioning, handling, transport, and storage of PV for repair, reuse and recycling. Develop new standards and guidelines for reuse of solar panels including testing requirements and covering export opportunities.	Clean Energy Council, Smart Energy Council, Industry stakeholders	2026
Implement environmental labelling and panel standardisation to reduce variability between panels	PV recyclers, manufacturers, Smart Energy Council, Clean Energy Council, IEA PVPS	2027
Education and training for improved consumer and installer awareness, and silicosis safety training for recyclers.	State governments, industry bodies	ongoing
Research and Development for commercially viable 'good practice' PV recycling and develop domestic end-markets for recovered materials	Australian Renewable Energy Agency, state governments.	ongoing