Reclaimed PV Panels Market Assessment Industry Report

APRIL 2023

Circular PV Alliance

The University of Queensland Australia

Acknowledgements

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CPVA is focused on identifying and developing the necessary tools and strategies required to enable a more sustainable and thriving solar energy sector. CPVA collaborates with various industry partners to undertake research and projects to understand and realise the potential of the solar energy circular economy. A core aspect of CPVA's work is to focus on practical, commercial solutions that enable the self-determination of various stakeholders and market participants.

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Executive Summary

The University of Queensland and Circular PV Alliance have prepared this Reclaimed PV Panels Market Assessment to explore the end-of-life landscape for used PV panels. The focus of the research is on understanding potential customers and value streams for used PV panels, and to identify any market or policy barriers to reusing, repurposing and recycling PV panels.

Research was conducted via a literature review and a series of interviews. The interview cohort comprised thirteen (13) organisations with diverse interests in solar energy, the recycling sector broadly, and PV panel reuse and recycling. Thematic analysis of the interview transcripts identified a series of recurrent themes that indicate potential or perceived opportunities (drivers) and challenges (barriers) for PV panel reuse. These themes fall into four (4) main categories – Policy, Consumers, Industry and Legal. These categories also serve to identify the potential roles and responsibilities of each group in used PV panel markets.

There is broad concern amongst interviewees that functional PV panels are being decommissioned before they fail and prior to fulfilling their productive lifespan. Key drivers of used PV panels in Australia are renewable energy certificates, the failure rate of low-quality products, residual PV panels from solar farms, warranty and insurance claims and performance limitations between different PV panels. It is predicted that Australia will have around 450,000 tonnes of PV panel 'waste' by 2040. This volume may increase depending to what extent solar energy contributes to Australia's renewable energy mix in future.

Once decommissioned, PV panels have historically followed a linear or 'take-make-dispose' lifecycle which results in them being sent to landfill. This is problematic for a range of environmental, social and economic reasons. A PV panel has significant residual value when removed from service through its technical capability to generate clean energy and the embodied value of its materials. Used PV panels offer a low-cost and affordable clean energy option for households and community energy projects. Concurrently, PV panel recycling processes are becoming more efficient with better quality outputs and higher recovery rates. For example, nano-silicon created from processing recovered silicon solar cells can retail for over $44,000 per kilogram.

Research found that the challenges identified in literature or presented by interviewees regarding recycling or reusing PV panels may be successfully remedied through different policy frameworks, legislative mechanisms and provision of commercial services. In most cases there are successful examples of similar solutions already in place around the world. Viewing used PV panels as an asset and keeping them out of landfill through a value-capture system, such as a circular economic model, offers a variety of benefits and opportunities. This model loops the 'take-make-reuse' phases into a self-sustaining cycle. The model also provides a foundation to grow markets for used PV panels and responds to consumer demands for credible and sustainable products and services.

It is recommended that a consistent, national approach to product stewardship is adopted to give rise to the circular economy for PV panels and initiate establishment of successful markets for used PV panels. Mechanisms to incentivise participation and disincentivise non-participation in product stewardship are necessary. It is important that phases and activities within the circular economy are clearly defined, for example, what does it mean to refurbish a used PV panel or what level of material/parts recovery from a PV panel constitutes it being recycled. Standards for testing and certifying used PV panels, providing repair warranties, industry reporting or accreditation requirements and product traceability are all important elements to product stewardship and used PV panel markets. Targeted engagement with a broader range of potential consumers, the insurance sector and PV panel manufacturers is recommended to better understand the perceived barriers held by these groups regarding used PV panels, and to develop suitable solutions to mitigate these perceived barriers.

In summary, used PV panels are a source of social, environmental and economic value. Looming volumes of used PV panels and an ever-increasing amount of solar energy being installed in Australia provides the impetus to proactively create a circular economic model for PV panels that will benefit consumers, industry and the environment collectively.

Contents

Introduction

The University of Queensland was awarded grant funding by Energy Consumers Australia (ECA) to undertake a 'Reclaimed PV Panels Market Assessment'. Working in collaboration with Circular PV Alliance (CPVA), this research project explores the end-of-life landscape for used PV panels to understand potential customers and value streams available for used PV panels, and to identify any market or policy barriers to reusing, repurposing, and recycling PV panels.

Research was conducted via a literature review and an interview series. The literature review involved an analysis of current and available literature, reports, and other relevant documentation to gain an understanding of the solar energy market, the current end-of-life management of solar PV and existing options for PV panel reuse and recycling.

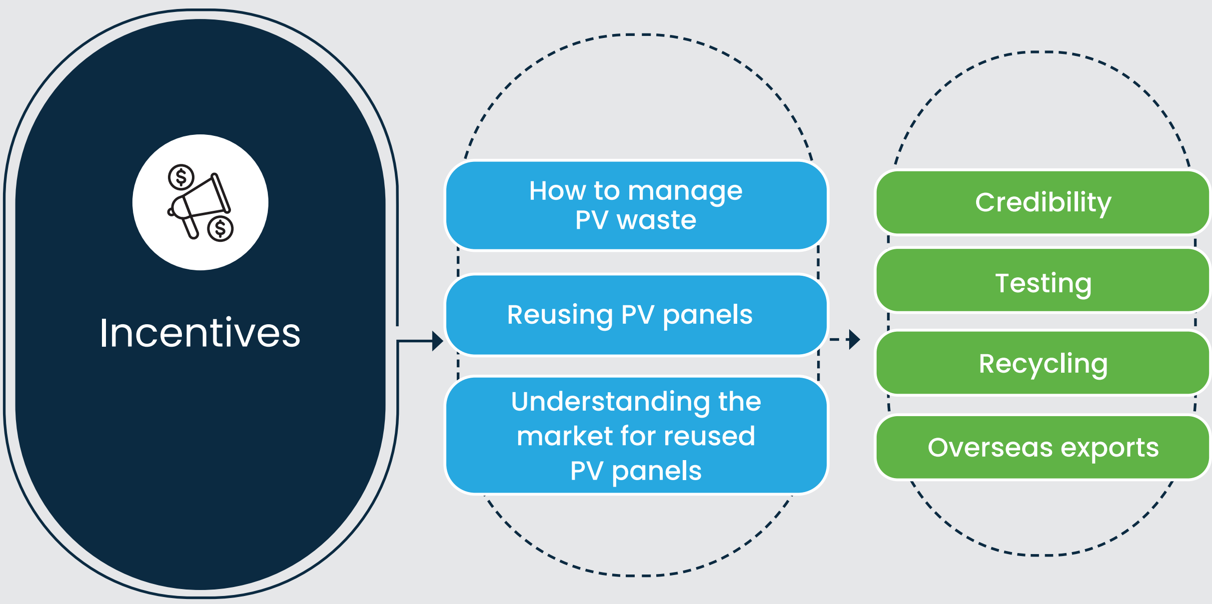
A number of industry stakeholders were invited to participate in an interview in order to obtain a range of perspectives relevant to the project. Thirteen (13) organisations agreed to participate as part of the interview cohort, with diverse interests in the solar energy sector, recycling more broadly, and PV panel reuse and recycling.

Collectively the cohort represents a range of industry bodies, potential user groups and various service providers (some with interests across multiple categories) with diverse practical, technical, and commercial backgrounds.

Interviews were guided by a set of questions, with participants also encouraged to explore used PV panels in ways that were relevant to them. The transcripts from these interviews were then coded to extract themes. Many themes were uncovered that were not directly part of the interview guide. This has provided a nuanced and more in-depth understanding of reclaimed PV panels and potential markets.

Thematic analysis (Figure 1) of the interview transcripts identified twenty (20) recurrent concepts throughout the interviews. Aggregating the concepts into dominant themes and sub-themes provides a macro level view of interviewees' perspectives regarding reclaimed PV panels.

FIGURE 1: THEMATIC ANALYSIS OF INTERVIEW TRANSCRIPTS



These key themes are reflected in the opportunities (drivers) and challenges (barriers) for PV panel reuse presented in this report. There are four (4) main categories to group the drivers and barriers which also serve to identify potential roles and responsibilities: Policy, Consumers, Industry and Legal.

'Incentives' was the most commonly mentioned theme in the interviews, including the use of incentives in relation to promoting PV panel reuse and also in promoting the uptake of rooftop solar. Incentives are viewed as a critical part of promoting PV panel reuse and recycling by interviewees.

Managing and reusing PV panels, and understanding the market for reused PV panels were secondary themes. This highlights the need to continue developing and communicating solutions for reusing PV panels.

Other common themes such as testing and certification form part of the reuse landscape, with recycling and exports also part of the solution.

Research found that the challenges identified with recycling or reusing PV panels may be addressed through different solutions or mechanisms. These solutions generally present policy and commercial opportunities, and in most cases there are examples of similar solutions in place around the world.

One example is the need for a supportive and effective policy and legislative framework to drive more sustainable or 'circular' industry practices which has been in place in the European Union for over a decade. Australia's *Renewable Energy (Electricity) Act 2000* [1] affords a range of incentives and regulatory requirements for different groups which resulted in the exponential growth of domestic roof-top solar uptake in Australia. This combination of incentives and regulations offers a proven template to drive a similar outcome for used PV panels, as discussed in this report.

Solar energy in Australia

10%

10% of national energy generation in 2021

31%

Increase in solar energy generation from previous year

100M

Estimated 100 million individual PV panels in Australia end 2022

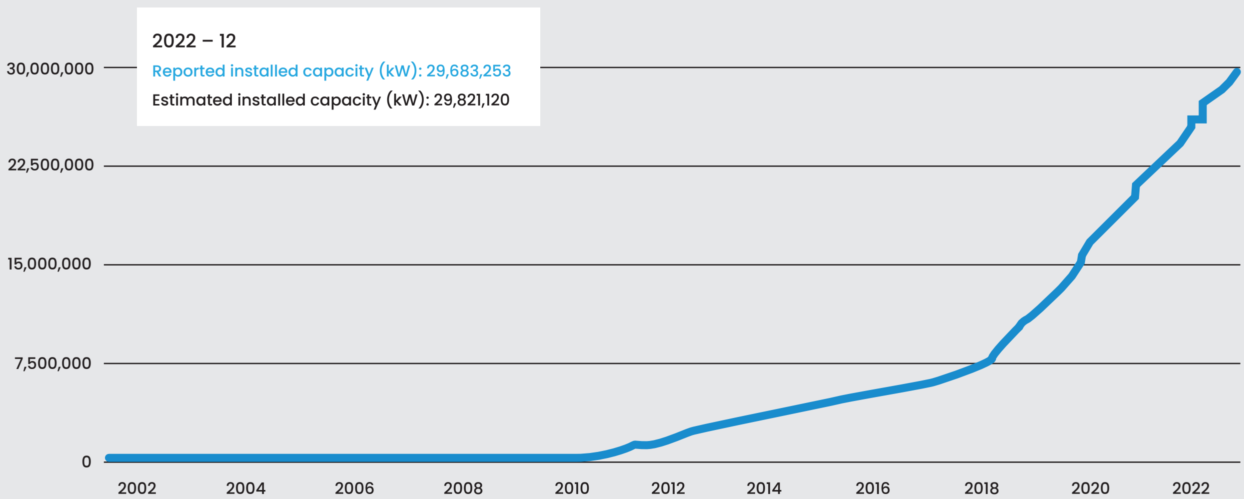
Renewable energy is a growing contributor to the overall energy generation mix in Australia. Renewables accounted for 29% of national energy generation in the 2021 calendar year [2]. Solar represented around 10% of total national energy generation for the 2020-21 year which is a 31% increase in generation from the previous year. The growth trend is clear and is supported in data provided by the Australian PV Institute [3] which shows an ongoing upward trend of installed solar energy generation capacity in Australia since 2010 (Figure 2).

Australia has enjoyed a buoyant solar energy market for over a decade. Current estimates indicate there may be around 100 million individual PV panels in Australia as of the end of 2022. Renewable energy, including solar PV, is experiencing an increasingly favourable policy environment as the different levels of government look to secure pathways towards achieving Australia's 2050 Net Zero emissions target.

The sheer number of PV panels that are likely to be needed to achieve this target is massive. According to some scenarios, an additional 1,900 gigawatts (GW) of solar energy is required [4]. The highest wattage PV panel available today is 700W. Allowing for technological gains in panel efficiency over time, if we assume 700W might be the average panel size in future, that equates to over 2,700,000,000 (two billion 700 hundred million) PV panels needing to be manufactured and installed to achieve an additional 1,900 GW of solar energy.

FIGURE 2: SOLAR ENERGY GENERATION TRENDS IN AUSTRALIA

Australian PV installations since April 2001: total capacity (kW)



(Source: Adapted from APVI)

Achieving Net Zero will require a suite of mechanisms to address policy gaps, open implementation pathways, develop grid capacity, advance technology and achieve social acceptance of the renewable energy transition. Australia's current reliance on importing PV panels exposes our renewable energy ambitions to external market influences. The Chinese government recently announced it is considering limiting exports of advanced solar technology [5] used to manufacture large solar wafers, black silicon and ultra-high mono-crystalline and multi-crystalline silicon. Such an outcome has potential to increase import costs exponentially and impact the renewable energy transition.

Prices for lithium, cobalt, silicon, steel, aluminium and copper have also soared recently. A recent article by PwC [6] predicts the pressure of the global energy transition and geopolitical dynamics will further escalate the cost of critical energy minerals embedded in renewable technologies. Overlay the fact that multiple other countries also have lofty solar energy targets and will be looking to source products from the same supplier pool, and an alarming scenario begins to emerge indicating a looming 'bull' market at its core – to the detriment of solar PV consumers like Australia.

This paradigm presents an opportunity to transform Australia's energy, manufacturing and waste management industries into an integrated, circular economy as part of the renewable energy transition. Australia is forecast to have one of the most significant accumulated PV waste streams in the world [7]. Conversely, this also highlights the ready availability of feedstock on hand to kickstart new domestic markets to respond to this waste stream. A circular economy for solar energy opens a myriad of opportunities to re-evaluate Australia's global contribution to clean energy generation.

> Renewables accounted for 29% of national energy generation in the 2021 calendar year.

PV panels – from waste to asset

Australia is forecast to have up to 450,000 tonnes of solar PV panel 'waste' requiring some form of management and handling by 2040 [8]. Solar PV panels contain a variety of valuable materials. A shift towards viewing a PV panel as a valuable resource or asset in preference to 'waste' will improve both consumer and industry level understanding of the inherent value of a PV panel, even if it is not brand new.

Circular PV Alliance (CPVA) has found that many PV panels are removed or replaced at around 10 years old. Although from a limited data set, these could be seen as the 'first wave' of PV panels installed during Australia's incentive-based approach to drive rooftop solar energy uptake around 2010 which saw a spike in installations across the country.

Technological advances have vastly improved the efficiency of PV panels in the last decade. Ongoing financial incentives through the renewable energy certificates (RECs) scheme encourage property owners to replace existing solar energy systems well before they have reached the end of their design life, and often with much larger systems. A 'working' PV panel still holds inherent value, as discussed later in this report.

Research conducted for this project, including interviews with industry stakeholders, indicated other regulatory, licensing and warranty arrangements also restrict the re-installation of solar energy systems. For example, one interviewee described cases where a solar array might have been removed (to repaint a roof for example) and was otherwise safe and fully operational, but could not be reinstalled due to such restrictions.

CURRENT TREATMENT OF USED PV PANELS

Solar PV panels have historically followed a linear or 'take-make-dispose' lifecycle (Figure 3) [9] in most countries, including Australia, which means most used PV panels have been sent to landfill. Europe is more advanced in dealing with used PV panels. In 2012 the European Union revised its Waste Electrical and Electronic Equipment (WEEE) Directive [10] to implement 'extended product responsibility' (ERP) regulations for the collection and recycling of PV panels, including setting minimum collection and recovery targets. Producers and importers of electrical and electronic equipment (including solar PV) are required to organise (and report on) the collection and waste treatment of their products, and the financing of these activities.

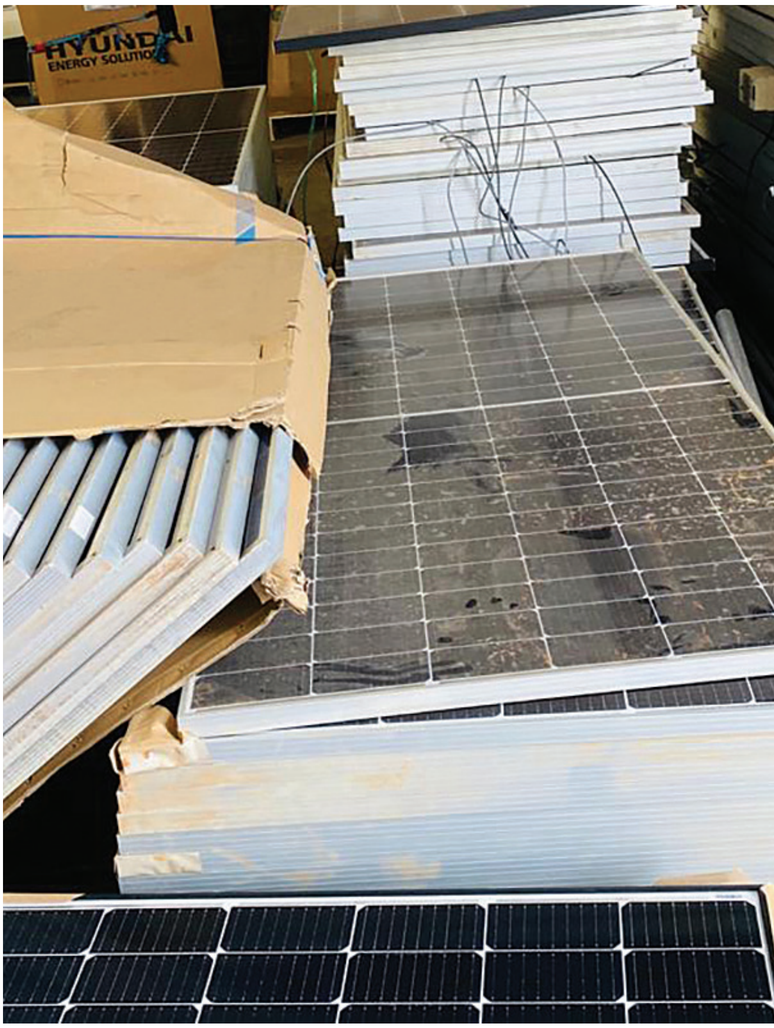


FIGURE 3: A LINEAR OR 'TAKE-MAKE-DISPOSE' PRODUCT LIFECYCLE

(Source: Adapted from Wautelet, 2018, ResearchGate.)

In Australia and the United States where this type of legislation has very limited application, research and feedback from interviewees found that attempts at preventing used PV panels from entering landfill have resulted in vast quantities of decommissioned PV panels being stockpiled in warehouses. Recent policy changes and policy reviews in several states (most notably Victoria, South Australia and Queensland) now categorise PV panels as e-waste and subsequently require specific end-of-life management procedures. In practice, this diverts 'whole' PV panels from being disposed of at landfill sites however it does not prevent 'parts' of solar panels being disposed of in landfill as 'residual waste' from recycling processes, or PV panels being shipped interstate to circumvent policy requirements.

PV recycling businesses are emerging around the country with differing recycling processes or technologies on offer. Currently, most PV recycling technologies adopted around the world focus on recycling materials that consist of the majority of the weight of the module, such as the aluminium frame, glass and copper, using basic crushing processes to meet legal requirements [11]. In the most basic scenarios, rudimentary recycling activities occur to remove only the aluminium frame and the remainder of the PV panel (and its embedded valuable resources) is thrown out. This situation highlights possibly an unintended 'loophole' in some policies, and concurrently reinforces the necessity to adopt appropriate compliance frameworks in conjunction with policy mechanisms.

DRIVERS OF USED PV PANELS

There is broad concern amongst interviewees that functional PV panels are being decommissioned before they fail and prior to fulfilling their productive lifespan. Some interviewees identified there is a trend for PV panels being decommissioned earlier and earlier into their lifespan, with functional (undamaged) panels as young as 3 years old now regularly being removed. In some instances, PV panels are being removed before the embodied carbon associated with manufacturing processes is abated by the panel's clean energy generation [12]. PV panels are generally removed for two main reasons: technical issues (a faulty product or damage such as from a hailstorm) or consumer-driven upgrades to new technology.

Renewable energy certificates (RECs)

The Renewable Energy (Electricity) Act 2000 [13] was introduced to:

- encourage the additional generation of electricity from renewable sources,
- reduce emissions of greenhouse gases in the electricity sector,
- ensure that renewable energy sources are ecologically sustainable,
- contribute to the achievement of Australia's greenhouse gas emissions reduction targets.

The Renewable Energy Target (Figure 4) is an Australian Government scheme designed to achieve the objectives of the Act and works by allowing large-scale power stations and the owners of small-scale systems (such as residential rooftop arrays) to create 'renewable energy certificates' (RECs) for every megawatt hour of power they generate. Small-scale renewable energy systems create small-scale technology certificates (STCs) and large-scale power stations create large-scale generation certificates (LGCs). These certificates are then purchased mostly by electricity retailers to meet the retailers' legal obligations (to source certificates) under the Renewable Energy Target.

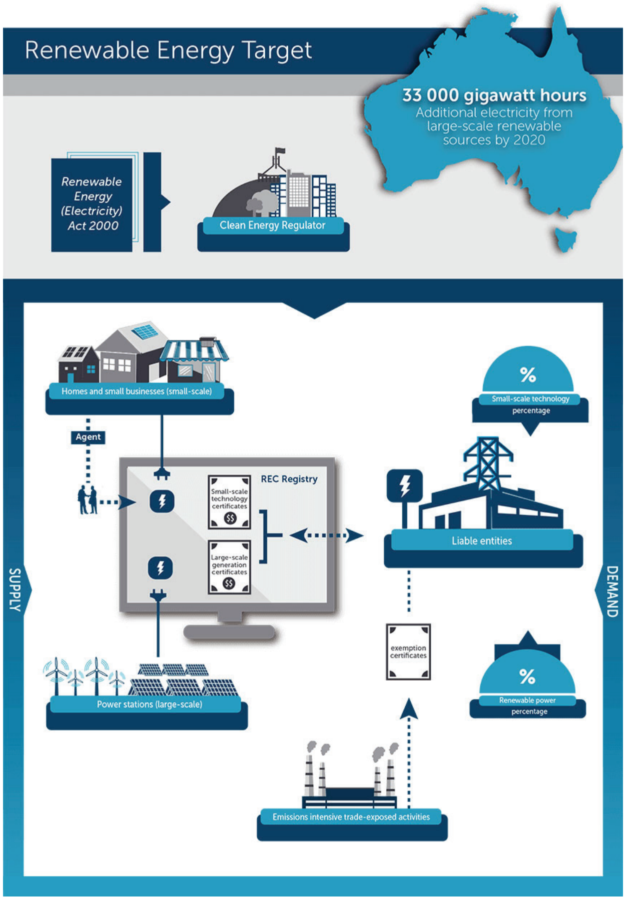
The value of an STC is determined, in part, by the forecast length of time that the PV panel will be generating clean energy, also known as the deeming period. The deeming period was set out by the Renewable Energy Target scheme (with a maximum period of 15 years) and was always intended to be phased out and cease to apply by 2030. A panel installed in 2010 for example has a (capped) 15 year deeming period. '15' is then used as a multiplier to calculate the number of STCs the system is eligible for and ultimately, what discount may be applied to the overall cost of the system through the sale of the STCs.

STCs can only be claimed against a list of new, accredited PV panels pre-approved by the Clean Energy Council (CEC). STCs cannot be claimed for PV panels that have already had RECs claimed [14], which would include the bulk of PV panels in Australia, including safe and functional used ones. This scheme and legislative framework were designed to create financial incentives to promote a renewable energy market in Australia, which it has successfully done. An unintended consequence over time has been the generation of discarded PV panels as consumers (both large and small scale) look to upgrade their solar energy systems with more productive technology.

Upgrading to a more productive system in itself is not necessarily a negative outcome. However the structure of the RECs scheme (and this is most prevalent for small scale systems) is that it allows for the original system and PV panels to be replaced within the deeming period of the original STCs, with new STCs being attributed (and paid for) again for the same remaining deeming period. The original STCs may have already been bought, and could still be bought in future, for clean energy generation that never actually occurs.

This has created a commercial model that simultaneously promotes the consumption of new PV panels and actively discourages the use of used PV panels. This is a linear product lifecycle and is arguably at odds with the objectives of the *Renewable Energy (Electricity) Act 2000*, particularly one of the core objectives to ensure that renewable energy sources are ecologically sustainable.

FIGURE 4: AUSTRALIAN GOVERNMENT RENEWABLE ENERGY TARGET



(Source: Department of Energy, Climate Change, the Environment and Water, Australian Government.)

Failure rate of low-quality products

Poor quality is another factor driving an increase in PV 'waste'. Australia's incentive-based approach to promote residential rooftop solar resulted in a spike in installations and also an influx of PV panel importers capitalising on the burgeoning market.

Despite Australian quality standards, some inferior quality PV panels were imported and installed throughout Australia. This has created a substantial legacy waste issue which is well documented in the media and well known to consumers [15]. With no stewardship scheme in place, there is no mechanism to determine or enforce accountability.

The type of failure will determine the pathway for a PV panel, for example, water ingress will generally result in the PV panel needing to be recycled and embedded resources recovered. An interviewee provides an example of a type of failure due to poor quality:

INTERVIEWEE QUOTE

> Is the backsheet actually an appropriate material? Not just contact adhesive that they got from a corner store? These are all true stories like panels where the back sheet just falls off within a few weeks in the sun, because it was made of contact...

The failure of a backsheet however does not necessarily mean that the PV panel must be recycled. Refurbishment of the backsheet is a potential option to keep the PV panel functional. New products are coming to market designed to repair faulty backsheets instead of replacing the PV panel [16]. Repair, refurbishment and reuse practices accord with a circular economy and waste hierarchy which are discussed later in this report.

Residual PV panels from new solar farms

Australia's energy industry, driven predominantly by Net Zero targets, will rely on large utility scale solar farms being constructed to achieve the planned renewable energy transition. Insights from interviewees found that up to 10 – 13% PV panel damage is allowed for per project. A 50MW solar PV farm for example may have around 100,000 PV panels which may result in up to 13,000 residual PV panels that require processing. Given this damage allowance, there is likely to be an increasing availability of residual PV panels from solar farm construction in Australia.

The nature of the damage determines the pathway of each PV panel for either repair and reuse, or recycling. FabTech Solar Solutions in the United States is a commercial operation that receives used PV panels and processes them to determine suitability for reuse (including testing, repair if needed and resale) or recycling if the PV panel has irreparable damage. In addition to condition, one of the determinants of whether a PV panel is suitable for reuse is its power output. Only PV panels of at least 250W are considered for reuse to meet consumer demands and also to make the process of preparing a used PV panel for reuse economically viable, as the cost of a solar PV is partially determined by its wattage.

In the US market, used PV panels sell for about 25% of the cost of a new one, making them very appealing to consumers. As Australia edges closer to 2030 and the end of the deeming period for STCs, used PV panels may become an increasingly attractive option for Australian consumers.

Warranty and insurance claims

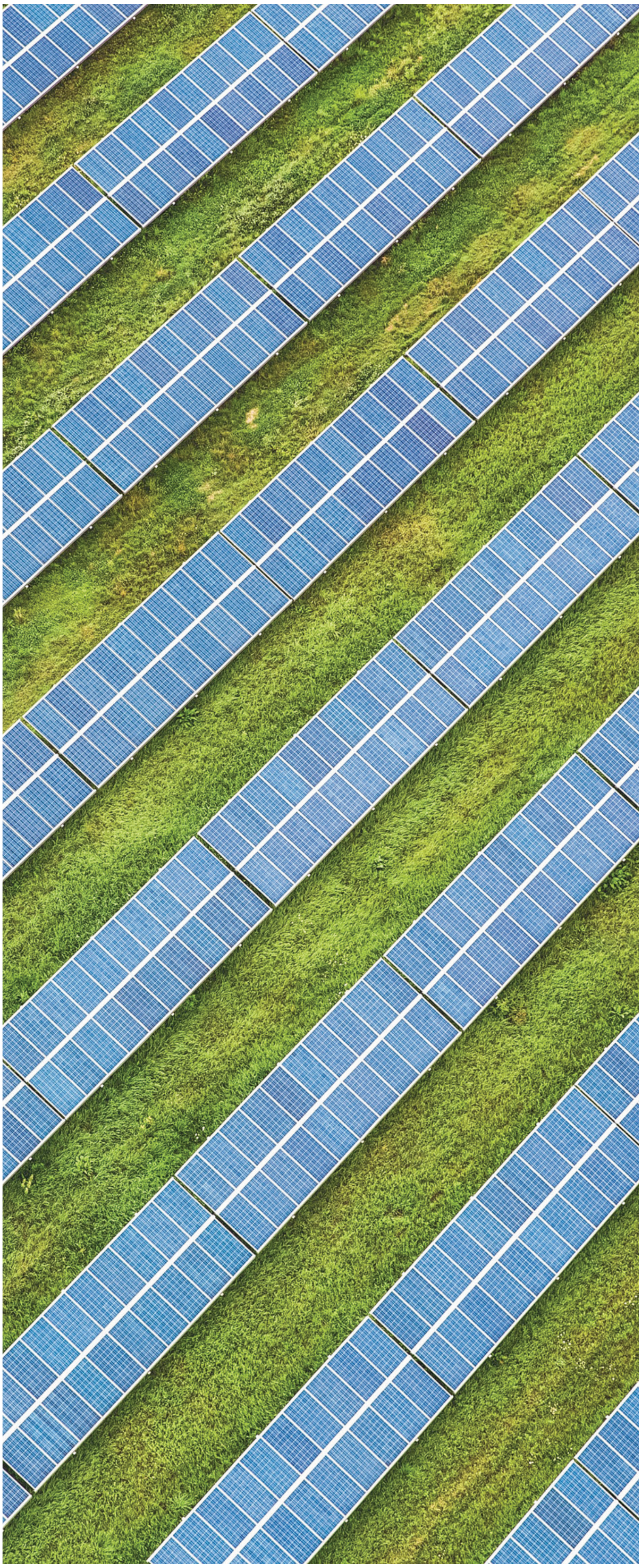
Examples were provided by interviewees around warranty claims for PV panels, where manufacturers opt to replace the entire array of PV panels with new ones when there may only be a fault in one or two. Similar examples are known for insurance claims. There are in-situ testing processes that can be undertaken to identify specific faulty PV panels in an array, however the relative expense and time to carry out the test incentivises simply replacing all of the PV panels. In addition, the RECs scheme only applies when the full system is replaced, and not on individual PV panels.

Performance limitations between different PV panels

The performance of a solar PV array connected to a common 'string inverter' is governed by the capabilities of the lowest performing panel. For an array of identically performing PV panels this is not an issue. When this is not the case, the whole array loses performance. 'Optimisers' can help regulate the performance disparity between different PV panels. When only one or some PV panels in an array need to be replaced and identical (or close to) performing PV panels are not available, retrofitting optimisers may be beneficial to smooth the generation differential and avoid the need for a brand new system. However, the costs (expertise, parts, labour, time) of supplying and fitting replacement PV panels (including used ones) and optimisers, needs to be competitive with the replacement costs of a brand new system.

More cost effective to replace rather than repair PV panels

The average rooftop solar PV system size in Australia is 6.6kW and costs approximately $7,500 [17]. Some sales campaigns advertise this size system for around $3,500, fully installed. This price is achieved, in part, through RECs. This tilts the economics strongly in favour of replacing an old solar PV system with a new one instead of repairing an existing system. Consumer behaviours are motivated by financial incentives, with 82% of Australians installing solar PV primarily due to financial drivers [18]. Even if the relative cost of a new set of PV panels is comparable to the cost of a set of PV panels retrofitted with optimisers (as discussed above), consumers will be motivated by the attraction of a newer product where the perceived better economic value lies. This results in older PV panels, although still productive, being replaced before they reach their end of design life.



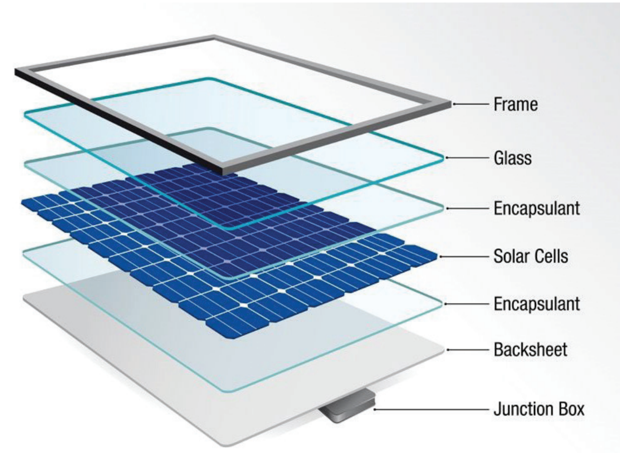
The value of a PV panel

The solar PV panel is a transformational technological innovation. Its ability to generate clean energy from the sun for an extended period of time rightly justifies its place in a renewable energy future. Solar energy, whether generated via new or reused PV panels, has the potential to play a major role in alleviating energy poverty. This means every PV panel is of value to humanity and each PV panel should generate energy (and provide value to people) for as long as possible.

From a material perspective, the relative value of materials in an average silicon solar panel is 47% silver, 26% aluminium (frame), 11% silicon (cells), 8% glass and 8% copper [19]. The silver content in PV panels is approximately 20 grams or 0.1% of a panel's weight.

Glass represents around 80% of a PV panel's weight. Materials recovery from PV panels is a developing technological space, with different mechanical and chemical recycling processes yielding different material recovery rates. The materials contained within a PV panel represent a valuable set of resources worthy of recovering.

FIGURE 5: THE PARTS AND MATERIALS OF A PV PANEL



(Source: The Scientific World)

RELATIVE VALUE OF MATERIALS IN AN AVERAGE PV PANEL

47%
SILVER

26%
ALUMINIUM

11%
SILICON

8%
GLASS

8%
COPPER

A recent advancement in recycling research has found a way to extract silicon from solar cells and process this into high-value nano-silicon [20]. Nano-silicon is used in lithium-ion batteries and can retail for over $44,000 per kilogram. Silicon recovery from solar cells and processing this into nano-silicon presents a very significant area for ongoing research and commercialisation.

Recycling is by far the most discussed and promoted outcome for used PV panels in Australia. The most common recycling practices in Australia are considered 'low recovery' as the recovered materials are generally not pure enough to be remanufactured in a new PV panel. However, material recovery rates and the quality of recovered materials appears to be improving both in Australia and overseas. For example, Solar Recovery Corporation is proposing to establish materials recovery technology at two sites in Queensland with a >99% material recovery rate [21]. Similarly, SolarCycle, a US based organisation, 'mines' resources from used PV panels and claims to extract 95% of the material value from a panel that can then be used to manufacture new panels [22].

The glass in a PV panel is a very high-quality, high-transmittance, tempered silicate glass. Recovering an in-tact sheet of glass from a PV panel offers significant embedded value due to its production process and inherent qualities of strength, durability and clarity. This is challenging to achieve though with limited examples of consistent success. Potential markets for intact PV panel glass sheets are unclear, however greenhouses and specialised construction projects are potential options. The current main outcome for solar PV glass is a crushed glass off-take material generated from recycling processes. Given the high quality of the solar glass, high-value applications such as manufacturing new PV panel glass need further exploration and will likely emerge as recycling processes evolve. Other products are coming to market that utilise the crushed glass as a sand replacement in building materials, such as SolarCrete [23]. Recycling to extract crushed glass from PV panels is most appropriate where the glass is damaged and the PV panel cannot be reused.

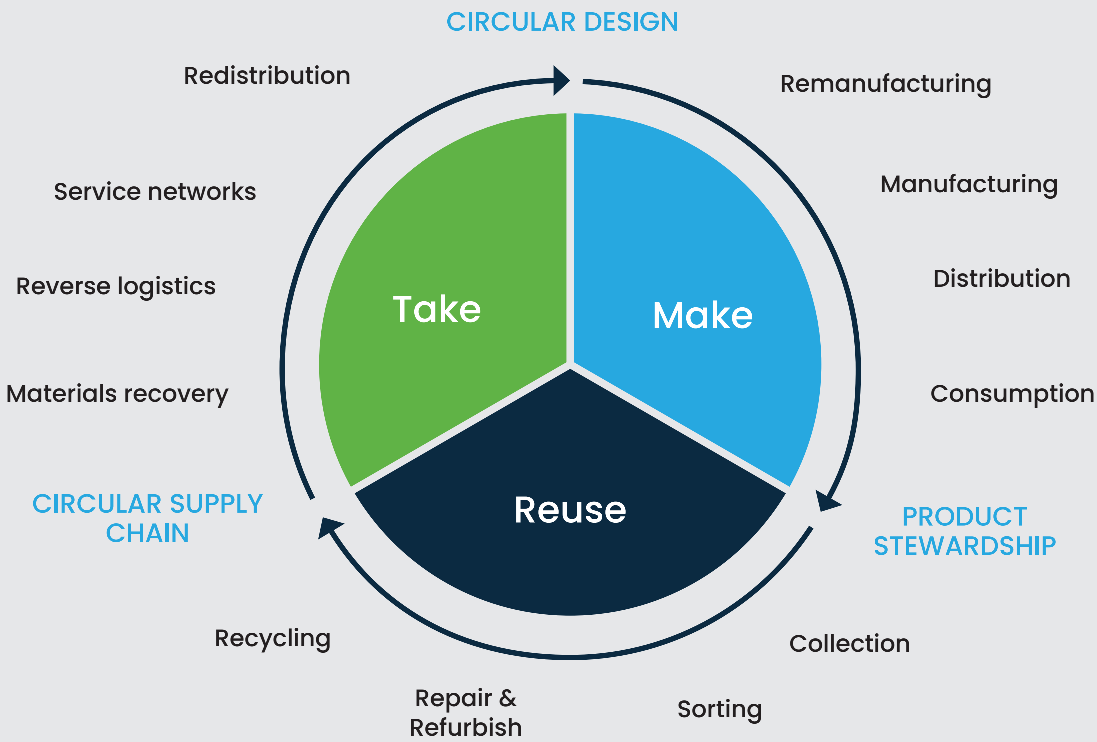
Used PV panels have significant embodied value in the form of materials and technological capacity to generate clean, low cost energy over a long period of time. Keeping functional PV panels in operation for as long as possible by reusing them and then recycling them to recover resources will reduce the volume of raw resources needing to be extracted to manufacture new ones. Thus PV panel reuse and recycling offers many environmental, economical and social benefits.

Value-capturing used PV panels

Research has identified that used PV panels have inherent value, whether that be in the opportunity to be utilised in a second life application or through recycling to recover embedded valuable resources. Systems and/or mechanisms need to be put in place to capture this value to benefit Australian industries and consumers.

A **circular economic model** provides the basis for a value capture system that responds to the challenges and opportunities of PV panel reuse and recycling identified in this research project. This model involves reuse and recycling to capture and re-embed value at different stages of the PV panel lifecycle. It is a shift from typical linear consumption typologies and involves holistic 'systems thinking', where 'take-make-reuse' phases loop into a self-sustaining cycle. The 'take' phase is different from the linear model as inputs are derived from the reuse phase as opposed to natural resources. This part of the report identifies and discusses important elements underpinning a circular approach to managing used PV panels.

FIGURE 6: A CIRCULAR PV PANEL LIFECYCLE WITH KEY DRIVERS BETWEEN EACH PHASE



REUSE BEFORE RECYCLING

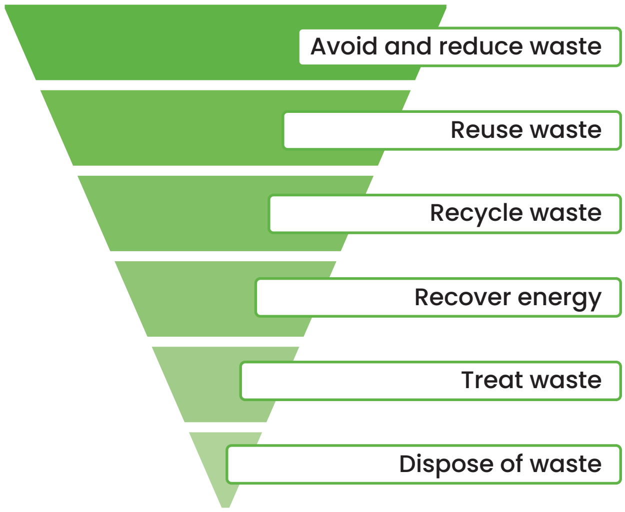
A circular economy calls for reuse prior to recycling. Where a used PV panel is functional with potential for redeployment to continue generating clean energy, then attention needs to be directed to facilitating that step in the panel's lifecycle. The *National Waste Policy 2018* [24] outlines a waste hierarchy where the action taken to manage waste is ordered in preference starting with avoid and reduce, reuse, recycle, recover, treat, and lastly dispose. The stages in a circular economy are mutually sustaining – reusing a PV panel reduces the need to use a new one, and increasing the efficiency of a PV panel through design and technology also reduces the volume of new PV panels required to generate a unit of energy (and the associated volume of resources needing to be extracted for manufacturing).

Diverting as much material as possible from lower order levels of the waste hierarchy avoids overburdening the supply chain and waste management systems. Presently, waste management infrastructure and supply chains are not ready to deal with a high volume of used PV panels. Once a PV panel is decommissioned it represents uncertainties for the supply chain, as summarised by an interviewee:

INTERVIEWEE QUOTE

> ...people don't know what to do with them...

FIGURE 7: THE WASTE HIERARCHY



(Source: National Waste Policy 2018)

The *Circular Photovoltaics* publication [25] references the ReSOLVE framework – Regenerate, Share, Optimise, Loop, Virtualise and Exchange – to maximise the use and lifecycle of a PV panel which largely aligns with the preferences outlined in the waste hierarchy. These actions require 'circular business models' at each stage of an 'asset's' lifespan to create mutual benefits amongst stakeholders and enable circular value chains. This sharing of mutual benefits between stakeholders could be seen as the convergence of Australia's energy, manufacturing and waste management industries into an integrated, circular economy. A system or scheme to guide appropriate handling of used PV panels will assist in facilitating this industry integration.

COLLABORATION IS KEY

Collaboration between all stakeholders including businesses, investors, industry and policymakers is central to optimising circular business models at each stage of the PV panel lifecycle, starting with circular design [26]. Interviewees expressed the importance of collaboration in driving change and identifying solutions. Clever design can promote reuse and enhance recyclability. Methods to assure circularity credentials such as material 'passports' and labels, extended producer responsibility (EPR) and product stewardship schemes, will be most effective if designed with stakeholders. Public-private partnerships to create scalable projects and case studies which validate a 'circular PV industry' are also important, such as the panel testing pilot project carried out by CPVA and PV Lab.

The bulk of Australia's solar PV deployment has occurred over the last decade. Local practices and research on how to manage discarded solar PV panels is not well established, but is an area of increasing focus by government and industry. The solar energy circular economy will need to overcome a variety of challenges specific to local conditions and influences to succeed. According to interviewees, managing vast distances and the impact on transport costs and logistics are important factors in Australia to consider. The literature and interview feedback highlighted the need for collaboration between stakeholders to develop solutions in order to strengthen the value proposition of the solar energy circular economy. Doing so will provide many opportunities to commercialise new services in relation to:

- Logistics for the collection and proper handling of discarded PV panels to maintain their condition for potential refurbishment and/or reuse applications,
- Developing new custom designed facilities or the integration of PV panel recycling machinery into existing waste or e-waste handling and recycling facilities,
- Creation of new supply chains for off-take materials and manufacturing enterprises,
- Developing independent certification processes and platforms to assure product circularity.

PV LAB AND CPVA PILOT PROJECT

In 2021 CPVA and PV Lab carried out a pilot project to test a set of used PV panels against the highest industry testing standards for safety, performance and quality. The test results found that on average, the tested PV panels were still producing 96% of their original name-plate output, even with some of the PV panels being over 10 years old. Micro-cracking was not a major issue as anticipated. The final assessment was that the majority of the used PV panels were suitable for reuse. The PV panels will be reinstalled for ongoing performance monitoring. The next step is to develop a testing and certification standard for used PV panels in conjunction with other industry stakeholders to apply lessons learnt from the pilot project into a practical real world solution to promote PV panel reuse.

CONSUMERS EXPECT SUSTAINABILITY

The circular economy is closely aligned with consumer trends demanding more ethical and sustainable product choices. There is a growing expectation that businesses (and this could be extrapolated out to encompass industries as a whole) need to take a more active role in leading positive change [27]. Interviewees highlighted that in the absence of government action, industry stakeholders (such as manufacturers) were driving PV panel recycling to meet shareholder and consumer expectations around the sustainability credentials of brands and businesses.

In terms of a clean energy future, reducing emissions and transitioning to renewable energy sources is one side of the coin – on the other side is the consumer expectation that this be achieved sustainably and with integrity. Achieving Net Zero at the expense of other social or environmental factors does not meet consumer expectations and therefore has commercial limitations. Fortunately, this paradigm in conjunction with the growing popularity of solar energy, presents an opportunity to expand on the range of tools and mechanisms that can be deployed concurrently to drive a circular economy that meets consumer expectations, including:

- Developing product stewardship schemes will help create an ongoing, improved consumer perception of solar energy following recent media coverage of some of the industry's shortfalls,
- Government funding programs to incentivise PV panel reuse as a means to achieve ultra-low cost solar for domestic and international communities and alleviate energy poverty,
- Landfill bans to divert PV panels into testing, refurbishment, reuse, resource recovery and recycling pathways, and associated certification and assurance mechanisms to drive new industries and local market capabilities.

POLICY MECHANISMS ARE IMPORTANT

Other industries are well advanced in dealing with sector generated waste streams and product stewardship and afford many lessons for consideration by the solar energy sector. Current examples demonstrate collaboration between various stakeholders, including voluntary and co-regulatory arrangements between industry and government, to bring about desired behaviours and beneficial outcomes. One approach to managing used PV panels is to include them as part of e-waste management systems. An international example is the aforementioned **WEEE Directive** introduced in the European Union. A benefit to this type of legislative framework is that it enables a range of service providers to emerge to assist businesses meet their regulatory requirements. These service providers may be commercial businesses or not-for-profit organisations (such as PV CYCLE or CPVA through its proposed certification label) that can provide independent assurance of compliance with relevant legislation.

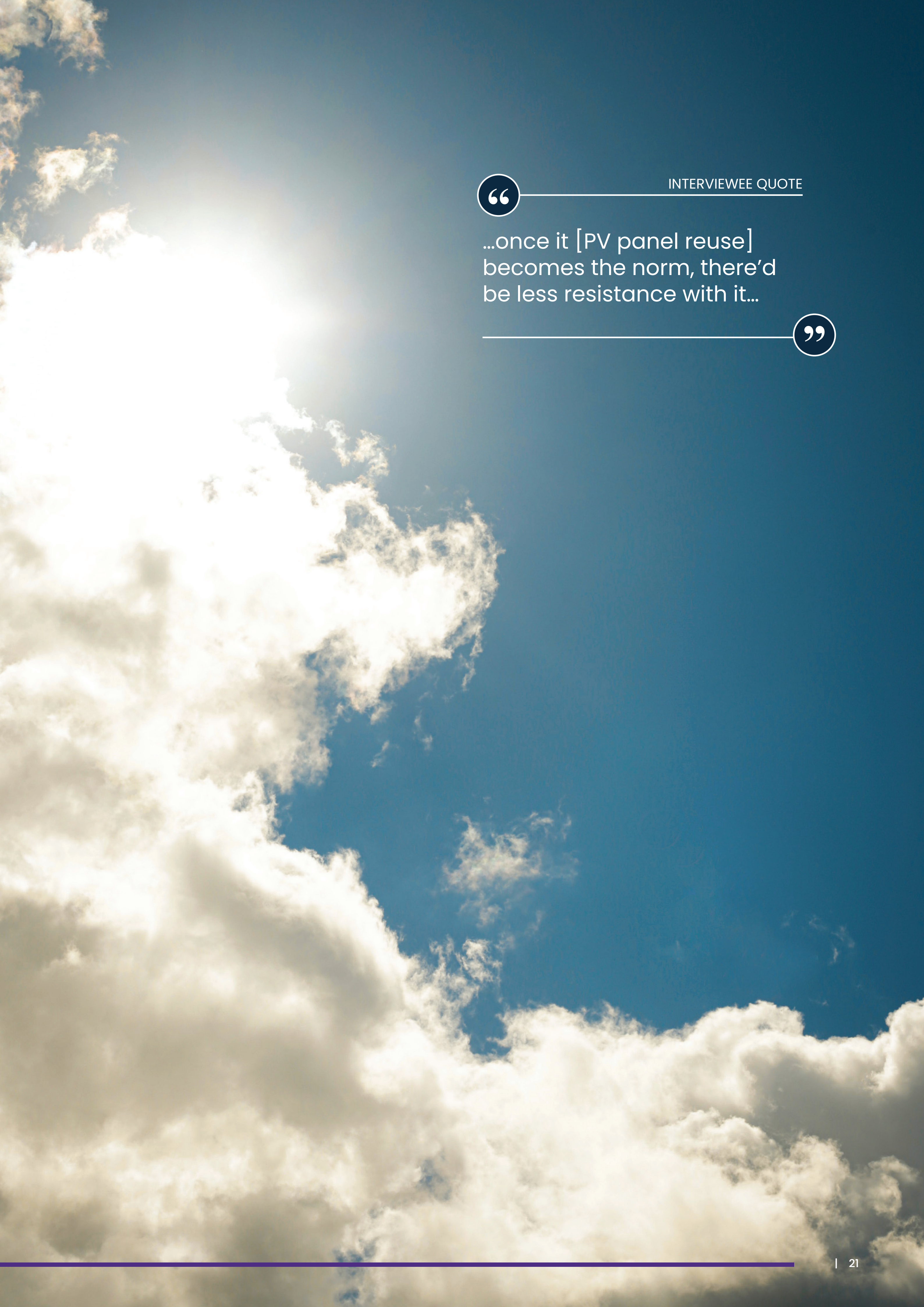
A 2019 study prepared for Sustainability Victoria and the (then) national photovoltaics stewardship working group found that a voluntary or co-regulatory approach for PV panel product stewardship is feasible and will improve management of materials and enhance resource recovery. In July 2019 the Victorian government introduced the **Waste Management Policy (E-waste)** [28] given effect under the *Environment Protection Act 1970* that bans the disposal of e-waste (including PV panels) into landfill. The Victorian government provided funding to support local waste management facilities adapt to the new e-waste management requirements. This policy decision has driven the creation of new businesses and services that offer drop-off points and collection services for used PV panels and new recycling operations.

The scheme has had varying success. Some drop-off points have reported very low receivership of used PV panels. The low rate of participation suggests that the voluntary nature of the scheme may need to be reviewed with a view to more mandatory requirements. Another issue has resulted from the lack of definition around what 'recycling' means. Interviewees shared known practices of only the aluminium frame being salvaged, with the remainder of the PV panel then dumped at landfill. This is clearly not in line with the intent of the scheme, but highlights another area for revision.

The **National Television and Computer Scheme (NTCRS)** is co-regulatory and run and funded by industry. Any organisation that makes or imports computers and/or TVs is required to "contribute funds to support the recycling of these products" [29]. A central aspect of the NTCS design centres on collection logistics, which includes drop off points around Australia to provide access to 98% of the population. The collection services range from permanent arrangements in retail outlets or at local waste transfer station for example, or temporary one-off event services.

The Battery Stewardship Council launched **B-Cycle Battery Recycling,** its battery stewardship program in February 2022 [30]. The voluntary scheme involves battery importers paying a levy to fund the scheme and incentives (including accreditation status and rebates) for scheme participants. Like the NTCS, drop off points are provided as part of a national network. The scheme is an Australian Government Accredited Product Stewardship Scheme and is authorised by the Australian Competition & Consumer Commission (ACCC).

These examples demonstrate success in achieving more sustainable product management outcomes in both voluntary and regulated schemes. The Victorian e-waste policy example highlights the need to clearly articulate definitions to ensure the desired outcomes are achieved. A central theme is also the need for a 'network' of touch points to access the system.



INTERVIEWEE QUOTE

…once it [PV panel reuse] becomes the norm, there'd be less resistance with it…

Reusing and recycling used PV panels

Understanding the barriers and drivers behind PV panel reuse and recycling markets will provide an effective foundation from which to build an effective circular economic model for PV panels. Insights from the literature review and interviews found that there are four (4) main categories to group the barriers and drivers: Policy, Consumers, Industry and Legal. These categories also serve to identify potential roles and responsibilities.

REUSING PV PANELS

PV panel reuse is a fledgling market that has potential for significant growth. There is a small market for used PV panels in Australia on second hand goods trading platforms such as Facebook Marketplace, Trading Post and Gumtree. A review of these platforms indicates that most used PV panels for sale appear to be from residential installations where the original solar array has been removed and upgraded to a new one. It is not known if any testing (for safety, performance or otherwise) was performed on the used PV≈panels for sale. Other online used PV panel marketplaces around the world include Solar Wholesale LLC, Salvex, Second Sol and Alibaba.

In the United States, a collaboration between FabTech Solar Solutions [31] and SanTan Solar provides a cleaning, testing, refurbishment/repair and resale process for used PV panels. Refurbished PV panels are offered as low-cost solar energy products for consumers. A 1-year repair and workmanship warranty is offered on each used PV panel sold.

Research has found that there is a divergence in perceived barriers around PV panel reuse. This is largely influenced by local market conditions, which influences consumer behaviours. In Australia, where solar energy is partially subsidised through RECs and subsequently relatively cheap (about AU$0.97/watt)[32], consumers are accustomed to low-cost PV panel products. Thus, the focus in Australia is more on the safety or performance aspect of used PV panels, given there is little concern about the cost of PV panels.

Safety and performance concerns can be alleviated through appropriate testing, repair/refurbishment and certification processes, and introducing liability/warranty mechanisms to meet Australian consumer expectations.

In the United States the solar PV market is very different. Consumers in the US pay about AU$3.40/watt [33] for new PV panels. Research shows that used PV panels in the US sell for around 25% of the cost of a brand new one. The used PV panel market then becomes very competitive simply by providing a lower price-point in comparison in brand new PV panels. Operators in the US market are therefore motivated to source used PV panels at low cost and focus on efficiencies in logistics to achieve a good profit margin.

The market conditions in the US potentially offer a glimpse into the solar energy future in Australia beyond 2030 after the STC deeming period ends. If brand new PV panels become more expensive in Australia it is likely that demand for quality used PV panels will increase.

A more recent practice has emerged in Australia whereby used PV panels, including damaged and unworking ones, are loaded into shipping containers and sent to overseas buyers. It is understood that the intent is, in most cases, to provide PV panels for solar energy projects in developing countries, which is a worthwhile cause. This is a two-fold problem for Australia: on one hand we are sending large numbers of PV panels that actually do not work and may be unsafe, to countries that have no infrastructure or services to responsibly handle these broken panels, and we could be seen to be imposing a waste burden on other less capable communities. On the other hand, highly valuable resources embodied in each PV panel are being sent out of Australia and out of our own commercial resource recovery and PV panel reuse markets.

Keeping used PV panels in Australia for reuse, recycling and resource recovery (and eventually to manufacture new PV panels) as a first priority is essential to driving a thriving domestic market in Australia. At a minimum, testing used PV panels for safety and performance prior to export or local application is a necessary part of the solar energy circular economy.

Barriers to PV panel reuse

Potential and perceived barriers to PV panel reuse need to be overcome to build a robust circular economy and associated product stewardship framework that will drive a used PV panel market. Our research uncovered several barriers to PV reuse:

Policy

- The current RECs scheme is perceived as competition to PV panel reuse as it provides financial incentives to use only new PV panels,
- The current RECs scheme does not 'incentivise quality' in terms of mechanical strength and energy output performance (certain old panels are generally stronger than some of the newer models),
- Resistance from levels of government to have reused PV panels in community projects in Australia because of the unknown history, safety or performance attributes of used PV panels.

Consumers

- Reuse is perceived to cost more than recycling a PV panel, particularly if testing for safety and/or performance is required,
- Perceived safety concerns, including fire risk,
- Perceived as an inferior product,
- Perception that consumers prefer new technology,
- Lack of information about the decommissioned PV panel and consumers desire to understand its condition and history.

Industry

- The logistics of receiving and processing PV panels for reuse at a commercially viable scale,
- Lack of certification and standards for reused PV panels,
- Potential for faulty panels,
- Manufacturers' hesitation for PV panel reuse.

Legal

- Legal agreements with manufacturers that are hesitant about PV panel reuse,
- Perceived liability issues, warranty limitations and compliance for residential use,
- Perception that insurance companies will not accept used PV panels for insurance work,
- Uncertainty for installers around liability and responsibilities regarding installing used panels.

Drivers for PV panel reuse

Despite the barriers mentioned previously, the literature and interviewees offer many drivers for PV reuse. This shows the landscape is improving in favour of PV panel reuse. A growing spotlight on product stewardship and a market shift towards circular business models will support PV panel reuse in conjunction with the following factors:

INTERVIEWEE QUOTE

> Members of the supply chain are compelled to participate in stewardship schemes to be seen to be 'doing the right thing'.

Policy

- Growing political interest in promoting circular economy solutions for industry,
- Current policy and support for renewable energy (such as Net Zero Target) can expand to include sustainable product lifecycles,
- The forthcoming end of the deeming period for STCs will end/reduce incentives to install new solar energy systems.

Consumers

- Consumers are demanding more sustainable and ethical products and services,
- Some older PV panels are of a proven quality to consumers, are robust and made to last many years,
- After the deeming period ends it will be cheaper to fix a PV panel than make a new one which makes reused PV panels attractive to consumers,
- Examples from around the world show repair warranties for used PV panels satisfy consumers.

Industry

- Global market influences (such as China halting export of solar cell technology, waste import/export bans) provide reason to establish and expand domestic industries,
- Most used PV panels still work, and they are predominantly being removed for reasons other than performance,
- Most used panels are generally easier to handle as they often weigh less than new ones and are smaller in size.

Legal

- Examples from around the world show that removing the serial numbers from used PV panels and offering repair warranties satisfies PV panel manufacturers concerns about liability and warranty,
- Introduction of landfill bans and other policies that support reuse and recycling.

Known markets for used PV panels

Used PV panels are being utilised in a range of projects and by organisations both domestically and abroad. Current applications and markets for used PV panels include:

- Low-cost solar carpark roofing,
- Urban non grid applications such as footpath and public park lighting,
- Low-cost solar energy products in overseas retail markets,
- Community energy projects by charities,
- Uninhabited dwellings related to community groups (that generally do not have much funding) such as sporting facilities, Scout halls, community garden etc.
- Overseas exports into developing countries in Africa, the Middle East and Asia, although this is proving problematic as previously mentioned,
- Agriculture infrastructure such as solar pumps, farm irrigation etc.
- Solar farms and off grid solar gardens,
- Outdoor recreation activities such as camping/caravanning, fishing, boating,
- Repurposed applications, such as PV panel tables with USB charging ports.

The continued operation of these activities needs to be supported to develop a circular economy. This will be achieved by bringing rigour and certainty regarding safety and performance of used PV panels. Facilitating easy access to lower order circular economy processes such as recycling (once a PV panel can no longer be used for energy generation) is also an important feature of the circular model.

Interviewees also stated that a prescribed level of testing and related certification for used PV panels similar to that required for new PV panels that are imported into Australia would be appropriate.

The Gippsland Climate Change Network (GCCN) has been investigating opportunities for used PV panels. In the report Recycling and Reuse of Solar Panels from 2021, the GCCN found that the prime markets for used PV panels include DC systems for caravans and touring applications and off-grid AC installations such as remote communities or farming applications (such as a remote pump). The key reasons for this being that used PV panels cannot be installed by a CEC approved installer on habitable buildings and they are not eligible for STCs. As such, the GCCN is targeting uninhabited dwellings such as town halls, sports facilities and farm houses for used solar panel projects including a local pony club and ground mounted solar gardens.

RECYCLING PV PANELS

Aside from being sent to landfill and the handful that may be resold on informal used goods platforms, recycling has been the most common outcome for a used PV panel in Australia.

Barriers to PV panel recycling

Research has found that the lack of a formal policy framework is the main barrier to PV panel recycling. Lack of consumer knowledge around recycling practices or what happens to a PV panel one it is removed is also a limiting factor. Logistics and transport are also challenging. Overseas recycling and recovered materials markets are more mature than in Australia and those markets are expanding. Key barriers to PV recycling include:

INTERVIEWEE QUOTE

"Collecting is not recycling, waste management is not recycling."

Policy

- Lack of effective policy mechanisms to encourage or enforce recycling,
- Lack of transparency and reporting obligations for recycling companies.

Consumers

- Low trust in PV panel recycling practices and claims about material recovery rates by recyclers,
- Historically low interest and knowledge by consumers about PV recycling (this is changing).

Industry

- Immature or non-existent markets for recovered materials,
- Recycling processes require high energy input which results in a poor lifecycle assessment score (which means current recycling practices have a notable environmental impact).

Legal

- Lack of licensing requirements or industry standards for PV panel recyclers,
- No tracking of decommissioned PV panels to confirm they are recycled,
- Australia's commitments under international agreements, such as the Basel Convention are unclear.

Drivers for PV panel recycling

PV panel recycling is already underway and is the most common activity in the PV panel circular economy. A largely self-defined sector at present, PV panel recycling will benefit from definition standardisation to clarify PV panel recycling activities. This will assist to map out key stakeholders and value chains, capture opportunities for growth and overcome potential barriers.

Policy

- Landfill bans and supportive policy and legislative frameworks, including product stewardship schemes and extended producer responsibility (EPR).

Consumers

- Consumers are demanding more sustainable and ethical products and services.

Industry

- Emerging markets and applications for clean materials recovery (like glass in construction products),
- A growing feedstock of used PV panels resulting from solar farm construction damage, faults or upgrades,
- Growing interest in domestic PV panel recycling capabilities to strengthen the sector against global influences, such as waste import/export bans,
- PV panels are a potential source for nano-silicon which retails for around $44,000/kg,
- Strong commodity trading market for aluminium (year average around US$2,300/tonne), aluminium maintains its quality after recycling processes,
- Resource scarcity for materials used to manufacture PV panels which increases market value and demand and makes resource recovery more attractive,
- Growing interest in domestic PV panel manufacturing capabilities.

Legal

- PV panel manufacturers have generally preferred their products to be recycled (instead of reused) to limit potential liability.

Creating a successful market for used PV panels

A successful market for used PV panels requires clarity and certainty around responsibilities and expected behaviours that are understood by stakeholders, market participants and consumers alike. Clear parameters for activities and services throughout the PV panel lifecycle will provide opportunities for circular business models across the value chain. Ideal principles to guide the establishment of an effective used PV panel market include:

Transparency

- Definitions of what activities and services form part of used PV panel circular economy, such as 'repair', 'recycle', 'refurbish', 'recover' etc.
- Expectations around resource recovery rates and quality of recovered resources,
- A clear product stewardship or extended producer responsibility (EPR) framework including regulation where necessary to appoint responsibilities, promote compliance and accountability,
- Inter-state coordination to ensure consistency of policy and compliance.

Assurance

- Standards for testing, repairing/refurbishing, classifying and certifying used PV panels that are industry agreed and independently verifiable,
- Accreditation requirements for service providers undertaking used PV panel testing and certification activities, and PV panel recycling,
- Warranties for used PV panels including repair workmanship and performance guarantees from manufacturers,
- Traceability and access to data relating to used PV panels including test results, certification and classification status, and also for PV panels sent for recycling.

Incentivised

- Reward operators and stakeholders in domestic supply and value chains within the solar energy circular economy,
- Fund ongoing innovation, research and development to drive efficiency across the circular economy, particularly around making testing quick and affordable and building logistics capabilities,
- Consideration of a similar RECs type framework to support PV panel reuse and recycling.

PUSH AND PULL MECHANISMS

Research indicates that a combination of regulatory requirements and supportive voluntary incentives can be used to drive a circular economy for solar energy. As previously mentioned, some PV panel manufacturers currently opt-in to recycling arrangements for their products as part of ESG (environmental, social, and governance) initiatives and market differentiation. This approach appears to be increasingly beneficial for those brands and businesses by enhancing their competitiveness, particularly in relation to sustainability requirements in government contracts.

Levels of government play an important role in enabling desired behaviours and driving industry change. At the national level, the government needs to define the process (product stewardship, EPR etc) and issue guidelines so that stakeholders understand their responsibilities. Policy mechanisms such as sustainable procurement (as mentioned above), industry reporting requirements, and funding support are other examples. Clear standards and requirements simplifies risk profiling and provides certainty for market stakeholders. Victoria's approach of assisting local councils develop supporting infrastructure for handling e-waste is a positive example of supporting behaviour change to achieve the intended outcomes of its new e-waste policy.

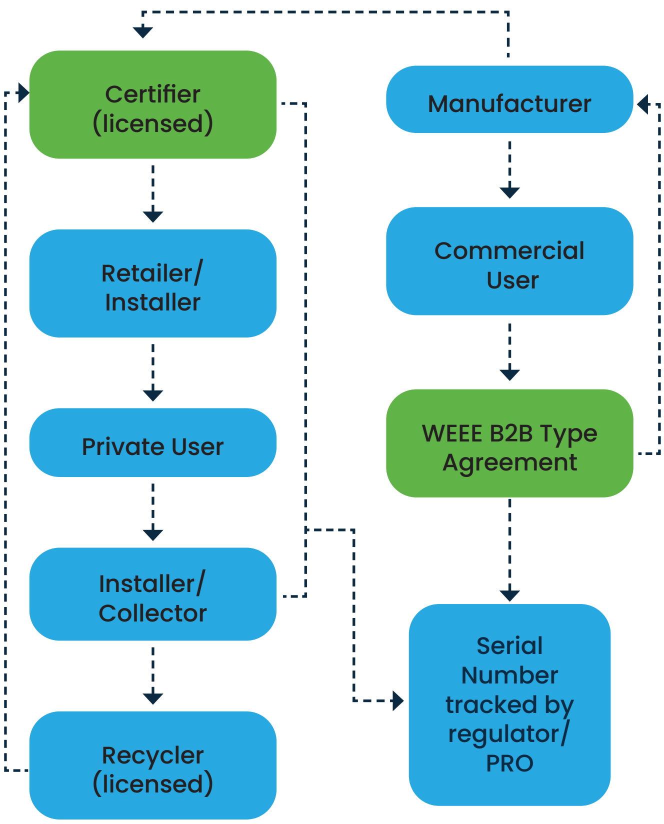
Regulations on PV recycling can unlock domestic production and manufacturing capacity as material flows can be directed to develop potential markets for recycling off-take materials. Effective regulation requires a level of enforcement. The use of disincentives or penalties needs to be carefully considered. Indirect disincentives can be achieved through a cleverly designed incentive scheme to provide pull mechanisms, encourage self-determination by industry stakeholders and avoid excessive 'red-tape' or perceived over-interference in the market by government.

For voluntary programs, disincentives could include import restrictions on international PV panel manufacturers and other market restrictions for domestic manufacturers that do not participate in the voluntary product stewardship or EPR scheme.

Offering incentives for retailers and wholesalers to only sell or promote brands that participate in the stewardship or EPR scheme are also indirect incentives to brands to encourage participation [34]. However, the sheer volume of used PV panels entering waste streams in the near future infers that a level of mandatory compliance in combination with incentives is likely appropriate. Mandatory requirements may also prevent the export of broken PV panels to overseas communities, as previously mentioned.

Another recent study [34] supports the research findings from this project that assuring the safety and performance of used PV panels is critical to driving a market for used PV panels. Providing this assurance requires some form of certification like a compliance certificate, as previously discussed in this report. The assurance framework is underpinned by a product identification and traceability platform to confirm compliance and satisfy consumers' expectations for industry integrity (Figure 8).

FIGURE 8: AN EXAMPLE OF A POTENTIAL FRAMEWORK TO CERTIFY USED PV PANELS



Source: Adapted from Majewski, Deng, Dias & Jones, AIMS Press Energy, 2023

NEW MARKET OPPORTUNITIES AND SERVICES

The circular model for PV panels in Australia will work most effectively across a network of service providers to respond to logistics, geographical distances and economies of scale needed to build the circular economy.

There are various stakeholders in the PV panel circular economy and other congruent sectors (such as manufacturing) that can play single or multiple roles according to their preferences and capabilities:

ELECTRICAL CONTRACTORS

PV panel decommissioning and packaging for transfer, installation of used PV panels.

LOCAL TRANSPORT OPERATORS

Collection and transfer of decommissioned residential PV panels.

INTERSTATE TRANSPORT OPERATORS

Bulk transfer of decommissioned PV panels.

USED PV PANEL PROCESSORS

Receiving and processing used PV panels for reuse including testing, refurbishment/repair work, certifying and rebadging ready for resale.

ONSITE TECHNICIANS

The size/scale of a PV panel installation that requires decommissioning may require onsite processing for more economical solutions.

RECYCLERS

Dismantling and processing PV panels to recover embedded resources as feedstock for other markets.

RETAILERS

Sale of reused PV panels including storing and online marketing.

MANUFACTURERS

Utilise recovered parts, materials and resources to re/manufacture new items.

METAL PRODUCERS

Melting and purification of recovered metals.

TECH DEVELOPERS

Product identification and tracing applications to assure the legitimacy of tested/certified used PV panels and recycled products.

CONSULTANTS

To assist in the establishment of new businesses and guide organisations to meet regulatory requirements.

RESEARCH INSTITUTIONS

To undertake ongoing research and innovation projects in conjunction with industry.

INTERVIEWEE QUOTE

> If we can get consumer protection right and good testing cost effective, then reuse is a better outcome than recycling.

Recommendations

The key finding from this research is that establishing a circular economy for PV panels does not need to involve 're-inventing the wheel'. Multiple strategies exist with proven performance in improving circularity. What is required is a **collaborative, cohesive approach** to assemble all the pieces of the puzzle together. There are examples of policy, legislation, regulatory frameworks, stewardship schemes, incentives and effective commercial models already developed and successfully implemented that can be integrated and made fit for purpose for a circular economic model for PV panels. A prime example is the policy and legislative package comprising the *Renewable Energy (Electricity) Act 2000*, Renewable Energy Target and Renewable Energy Certificates which stimulated Australia's rooftop solar sector.

Ongoing consultation and collaboration with industry stakeholders will further overcome barriers and identify solutions, including customised application of these existing frameworks and mechanisms. The drivers for PV panel reuse and recycling identified in this report substantiate a circular economy for PV panels and support the effort underway to achieve this.

These recommendations are intended to build on the work already undertaken to develop a more sustainable solar energy industry through different policy frameworks, legislative mechanisms or product stewardship studies. The recommendations reflect insights obtained from industry stakeholders and literature and have both practical and technical relevance.

A CONSISTENT, NATIONAL APPROACH

Building on the principles of Transparency, Assurance and Incentivised, a consistent national approach to policy and compliance measures will create clear parameters for used PV panel markets. This consistent approach could be achieved through either a product stewardship scheme or extended producer responsibility (EPR). As part of an integrated approach, it would be beneficial to align with parallel initiatives, such as the Australian Silicon Action Plan, the National Reconstruction Fund and international conventions (Basel for example) that Australia is signatory to.

It is recommended that work currently underway in this context, if it does not already do so, cover these matters:

Clear definitions

Prepare a set of clear definitions of activities undertaken by service providers and what phase of the circular economy that the activities are completed in, to avoid 'green-washing' or confusion, including but not limited to:

- What does it mean to **repair** or **refurbish** a used PV panel for reuse?
- What does it mean to **recycle** a PV panel? Or **recover** materials? What percentage of resource recovery from PV panels constitutes satisfactory 'recycling' for a scheme?
- What are the determining factors for whether a used PV panel may be suitable for reuse or recycling?

Standards

Setting standard requirements is another means of creating a transparent environment for the circular economy to operate within. Standards could be developed for processes (such as how to test a used PV panel for suitability for reuse). Standards could also be developed to specify minimum levels of material recovery and minimum value of recovered materials (to avoid downcycling) from PV panel recycling processes (also relates to definition above) to be considered an accredited 'PV panel recycler'. An important factor is to also consider established standards' potential applicability and use. Further engagement with industry stakeholders, particularly those with relevant technical, commercial and practical expertise, will assist in developing these standards.

Certification / Accreditation

Certification will provide assurance that the predefined standards for testing (and classifying) used PV panels have been met. Accreditation will provide assurance that the service providers certifying the products are following the correct standards.

Reporting

Reporting serves the dual purpose of maintaining trust between various stakeholders (service providers, consumers etc) and also in tracking the success of the stewardship scheme in achieving better, more sustainable outcomes for PV panels. Auditing and reporting are necessary to confirm compliance with certification requirements and standards in order to maintain accreditation. The regularity of reporting requires further investigation and needs to be considered in conjunction with developing certification and accreditation requirements.

Consumer Education

There is an opportunity to build on consumer expectations for more sustainable products and services. A consumer education and communication campaign will reinforce the need for and benefits of PV panel reuse and the steps being taken by industry (through testing and certification for example) to address concerns and build consumer trust.

PRODUCT STEWARDSHIP NEEDS TO INCLUDE PV PANEL REUSE

There is already work underway at a national level and to an extent at state level to develop systems and mechanisms to improve the handling of used PV panels. It is recommended that this work incorporates a full circular economy view of solutions for used PV panels. "Reuse" is a critical part of achieving circularity and involves promoting and supporting PV panel reuse prior to recycling or material recovery processes. The "reduce" phase of the circular economy needs to include looking at options on how to keep functional PV panels in-situ for as long as possible. Associated with that will involve considering product quality and longevity/lifespans as part of the stewardship model.

As demonstrated in this report, the perceived barriers to reusing PV panels can be overcome. There is a market for quality used PV panels and the focus needs to shift to building a framework that satisfies the various stakeholders involved in this market, including consumers, PV panel manufacturers, insurers and other service providers.

FURTHER RESEARCH

Like all consumer markets, consumer demand is a fundamental part of the used PV panel market. Understanding the potentially broad and varied needs to this market will assist in identifying the best and most effective methods of attracting and retaining a strong consumer base for used PV panels, particularly the reuse market. It is recommended that further research include:

- Specific research to identify and engage with a broad range of potential consumers about their perceptions, preferences and requirements when considering reusing PV panels,
- Targeted engagement with the insurance sector to better understand any potential or perceived barriers held by the sector regarding used PV panels, and identify suitable solutions to mitigate these perceived barriers,
- Targeted engagement with PV panel manufacturers to better understand perceived barriers regarding PV panels being reused after being removed from the initial installation, and discuss the solutions presented in this report (such as de-branding and repair workmanship warranties) or any other solutions to mitigate these perceived barriers,
- Specific research into developing and applying warranties for PV panels that are sold for reuse, including clearly setting out when legal/warranty obligations of PV panel manufacturers end and the chain of ownership and responsibility for used PV panels,
- Defining an appropriate process for testing used PV panels to determine suitability for reuse applications, and how best this testing information can be held (in a central database for example) and the life of the PV panel tracked.

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