Scoping study for photovoltaic panel and battery system reuse and recycling fund

Prepared for NSW Department of Planning, Industry and Environment by UTS Institute of Sustainable Futures & Equilibrium Consulting

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About the Authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney.

Equilibrium is a sustainability research and strategy company.

The authors acknowledge and respect the Aboriginal and Torres Strait Islander custodians of Australia. We continue to value the generations of knowledge Aboriginal and Torres Strait Islander Peoples embed within our community and we pay our respect to their Elders past, present and emerging.

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Contents

Acronyms

Acronym	In full
ACT	**Australian Capital Territory**
AEMO	**Australian Energy Market Operator**
APVI	**Australian Photovoltaic Institute**
CER	**Clean Energy Regulator**
EOL	**End of Life**
EV	**Electric Vehicle**
IEA	**International Energy Agency**
LGA	**Local Government Area**
LAB	**Lead-acid battery**
LIB	**Lithium-ion battery**
NSW	**New South Wales**
PV	**Photovoltaic**
R & D	**Research and Development**
ROI	**Return on Investment**
VIC	**Victoria**
VPP	**Virtual power plant**

Glossary

Term	Description
Downcycling	When the recycled material is of lower quality and/or functionality than the original material
Initial processing/ pre-processing	Initial processing that occurs prior to downstream processing for metals recovery, such as crushing or shredding
High recovery	A recycling pathway that seeks to recover high value form products at end of life
Low recovery	A recycling pathway that seeks to recover low value from products at end of life
Materials recovered	Materials diverted from landfill for use or further downstream processing
Participation rate	The share of discarded systems directed to recycling activities (equivalent to collection rate)
Product stewardship	A concept of shared responsibility by all stakeholders that aims to ensure that value is recovered from products at end of life
Recycling	The term used to describe the range of activities, including collection, sorting and processing, to recover used materials for manufacturing new products

Executive Summary

Background

The increasing waste stream from Australia's transition to renewable energy systems risks posing a major future waste management issue while detracting from the other benefits of renewable energy.

The International Energy Agency (IEA) forecast that Australia will have one of the most significant accumulated PV waste streams in the world. The recent market analysis by Sustainability Victoria (SV) indicated that PV systems will enter the waste stream in significant quantities from mid-2020, resulting from the solar boom in 2010 that was incentivised by generous feed-in-tariffs and federal government subsidies. It was estimated that approximately 100,000 tonnes of PV panels will enter the waste stream by 2035 Australia-wide, including approximately 30,00 tonnes in NSW. In the case of batteries, Australia is one of the leading markets worldwide for energy storage batteries. However, only 3-5% of all batteries (not including used Lead Acid batteries [LAB]) in Australia are collected for recycling.

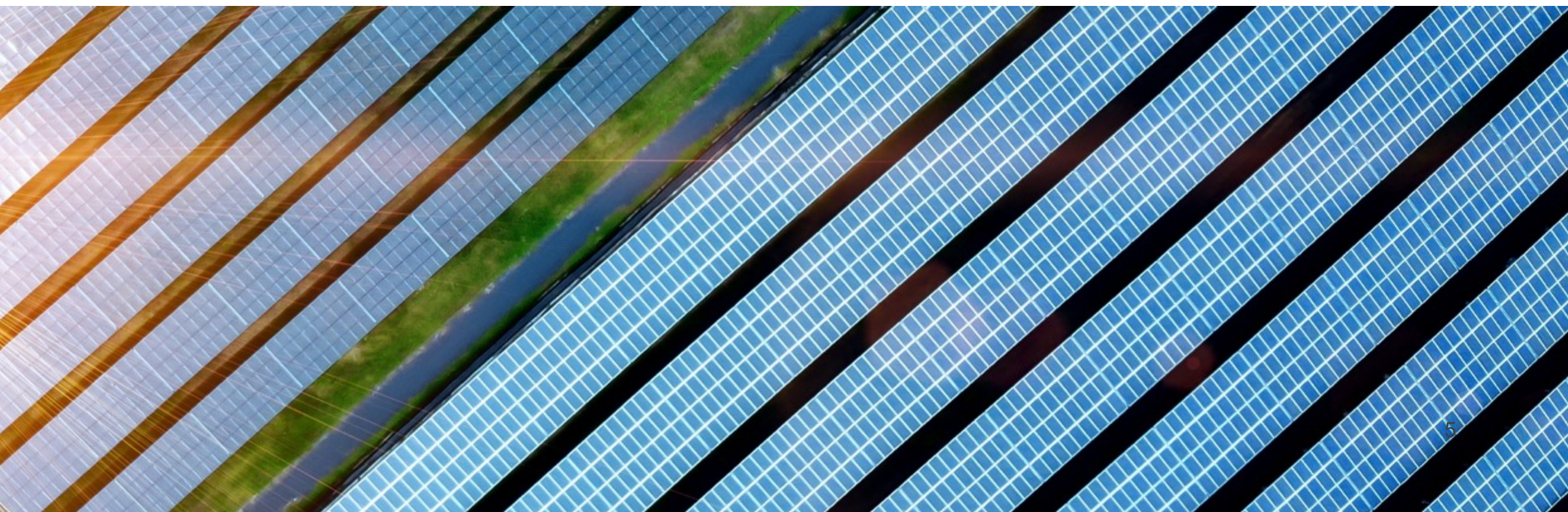
Nevertheless, there are also opportunities for the creation of new markets with the recovery of valuable materials. With NSW being only second to Queensland for the greatest monthly PV panel output by state, and a growing number of large-scale solar projects, it is well-positioned to take a leadership role in managing and future-proofing PV and battery waste management.

The $10 million fund from the NSW Government can help facilitate a transition towards closed loop systems for PV and batteries by accelerating the development of high-value recycling technologies and reuse systems. There is an opportunity to leverage the NSW Government investment to fast-track the National Project led by SV and by aligning with recently announced Federal Government support with ARENA's Research and Development Program Round 5: Addressing PV end-of-life issues and lowering the cost of PV. Furthermore, these initiatives complement the Clean Energy Finance Corporation (CEFC) $100m Australian Recycling Investment Fund and the CEFC's existing interest in and investment in solar and energy storage. While the current scope of the Recycling Investment Fund specifically targets plastics, glass, tyres and paper, this could apply to PV panels because of the glass waste stream and batteries because of the plastics.

Objectives

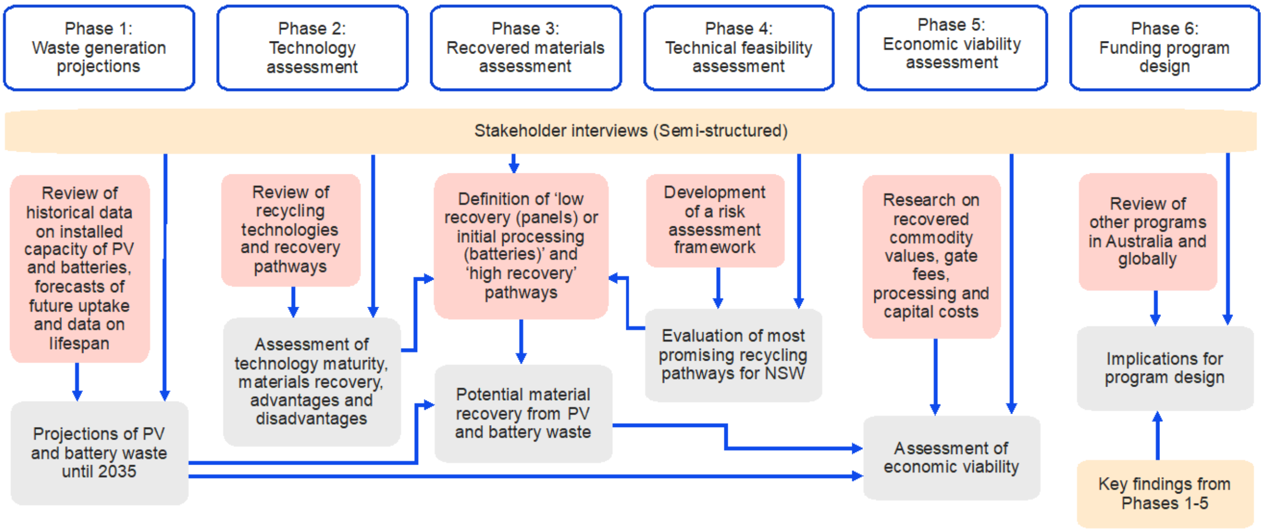
The aim of this project is to provide evidence-based research and design solutions to inform the development of an economically viable, environmentally and socially responsible program that adheres to circular economy principles. This was achieved through the following objectives:

- Estimation and characterisation of the waste generation potential from PV panels and batteries till 2035 in NSW and Australia
- Assessment of different collection, reuse/refurbishment and recycling technologies and systems prevalent in Australia and globally
- Identification and assessment of materials recovered from recycling and their end uses and end markets
- Assessment of the technical feasibility and economic viability of the most promoting collection, reuse and recycling methods in the NSW context
- Understanding stakeholder appetite and interest for the proposed funding program



Approach

The figure below maps the main activities in the project's six phases, and how they interact with each other. The specific methods and data sources for each phase are detailed in the corresponding sections of the report.



Stakeholder consultation

Stakeholders from industry and government were consulted to validate assumptions about waste projections, provide insights into current and emerging technologies for battery and PV panel reuse, refurbishment and recycling, and highlight any challenges and opportunities not captured in the literature. The insights from these interviews are highlighted in each section of this report.

Overview of Findings

Implications of findings from phases 1–5

Phase 1 suggested that waste from PV and batteries is currently low but will increase quickly. For PV, volumes of 3,000 to 10,000 tonnes per year are expected by 2025. Although battery waste grows at a faster rate than PV panels, due to their shorter lifespan, PV waste is projected to be 5 to 8 times greater than battery waste by 2035.

This phase also highlighted that waste volumes from distributed PV panels (particularly in Sydney, the Central Coast and Northern Coastal Regions) will require the most immediate action. However, systems to manage battery waste will need to scale up rapidly later in the period.

Phase 2 identified high and low recovery pathways for technologies that recover materials from PV panels and batteries. 'Low recovery' pathways, those that may not recover materials at a purity suitable for manufacturing new PV panels, characterised the current activity in Australia. While international examples of low recovery pathways can capture up to ~ 80 % further sorting and/or treatment may be required to manage a mixed residual stream, which has no identified end market. 'High recovery' pathways were identified that can recover intact silicon wafers and other metals; however, these require further development for commercial viability and to address potentially hazardous waste streams.

Phase 3 highlights a range of material recovery opportunities. For PV panels, the volumes recovered in the low recovery pathway depends on the crushed glass meeting market specifications, the potential for which is currently uncertain. There is a risk that this pathway could lead to glass stockpiling. For Lithium-ion batteries (LIB), volumes of black mass from the initial processing were estimated, highlighting that volumes from LIB from energy storage applications is relatively small. Comparison with high recovery pathways also illustrates the lost value when Co, Ni, Li is exported overseas.

Phase 4 revealed that recycling technology and systems will require some form of market intervention to ensure that both PV PV panels and batteries will have sustainable collection, reuse and recycling systems for projected volumes. It was found that battery recycling is likely to be feasible sooner than PV recycling in NSW, as they can be processed in facilities with diverse capabilities and capacity to scale up rapidly.

Phase 5 found that at present, the value of the commodities that can be recovered from PV panels and batteries does not cover the processing costs, which necessities a gate fee. In the case of PV, volumes are likely to become enough to make a low recovery processing facility financially viable (with a gate fee) from around 2025 assuming efficient collection. For a high recovery facility, volumes are likely to become enough by the end of the decade. Battery recycling may require less support to become viable because other initiatives and activities are supporting the development of a collection network. Further, the market can likely charge high gate fees and the recovered commodities are of high value enabling higher margins to be achieved.

Areas Requiring Further Research

1. Further research into the drivers and probability of early PV panel losses in NSW is required, including indicators of quality, early decommissioning due to single PV panel failure, and poor installation and maintenance.
2. R&D is required to further develop advanced processes for high value recovery for PV panels and the avoidance of contaminated residual streams from low recovery pathways. Treatment options for hazardous residual material also warrants further research.
3. For batteries, further research into the applicability of logistics systems for larger storage batteries is needed. More R&D may also be required to incentivise further battery recycling onshore.
4. Uncertainty around the quality of the recovered glass from PV panels in the low recovery pathway requires further research. R&D should focus on characterising crushed glass quality and the residual stream projected to arise in large volumes. Current uncertainty around the quality and market availability may result in stockpiling and undermine the economic viability of this pathway.
5. Further research into how recycling businesses may be supported by collection and aggregation of PV panels as free feedstock is recommended. Additional demonstration and pilot activities should also be developed to test collection and aggregation of PV panels for recycling and reuse.
6. Research to evaluate processes and economics for recycling differing battery chemistries is also required.
7. Further research into potential end markets and economics for glass recovered from PV panels will help inform future policy and investments.

Phase 1 – Waste Generation Projections

Objectives

The key objective of Phase 1 was to review the existing data on installation and waste generation rates for PV panels and batteries and develop waste projections for NSW until 2035.

Approach

To estimate projected waste volumes by 2035, a desktop review of industry and scientific studies was undertaken, including:

1. Historical data on installation of PV and batteries in NSW (including AEMO generation information, CER/APVI data, market studies)

2. Forecasts or scenarios of projections of installations and waste generation (such as 2020 AEMO Integrated System Plan, Sustainability Victoria PV and battery waste studies)

3. Data on products including average capacity (MW/unit), weight (tonnes/MW), lifespans (average lifespan in years) and reliability.

4. Data to be used for the projections was selected and segregated into in-front or behind-the-meter.

5. Interviews were conducted with 14 experts across industry, research and government to help verify and strengthen assumptions, particularly on average lifespans, as there is a lack of data on early losses of PV panels and batteries.

6. A material flow analysis (MFA) was undertaken to estimate the waste volumes for each technology in each year. A Weibull function was used to estimate when technologies would reach end of life (to account for early losses or products being used beyond their planned lifespan), based around two estimated average lifespans for each technology.

7. Data on PV installations by local government was mapped to understand where PV waste volumes are likely to arise in NSW.

Assumptions

Several assumptions informed the models for waste projection rates. These are outlined for PV panels and batteries respectively in the two boxes below.

PV Panels	**Batteries**
1. Historical installation data: Data on utility scale PV installations was from AEMO generation information page1 and APVI data on large scale PV Systems2, edited to include only grid connected solar farms. Data on existing distributed PV installations was from APVI data on large scale PV Systems3 (>100kw) and CER data on small scale installations4 (<100kw). The APVI data (which is compiled from historical CER data) was edited to exclude solar farms. **2. Future installation scenario**: Installation data for utility and distributed solar is from the AEMO 'Step Change' Scenario (2020 ISP).5 This scenario reaches the highest uptake of PV in the AEMO scenarios, reaching nearly 70% of installed capacity. **3. Average lifespan:** Average lifespans of 15 and 20 years were based on a review of literature and expert interviews. Current product warranties are generally 10 years and performance warranties 20 or 25 years. However feedback from interviews consistently indicated that there are a number of factors in the Australian market that are resulting in higher early losses than the data has predicted. These include: high rates of low quality, and sometimes fraudulent, panels being installed on rooftops; financial incentives to remove systems prior to end of life, disincentives to replace single rooftop panels rather than whole systems; lack of maintenance by owners; inappropriate installation locations. **4. Average weight:** Panel weight in the year of waste generation is based on a review of data of production weight by IRENA and IEA-PVPS. Weight has decreased over time from ~145t/MW in 1990 to an estimated 60t/MW by 2030. The shape parameter for the Weibull function	**1. Historical installation data:** Data on existing distributed battery installations is from CER data on small scale installations[4] (<100kw).[7] This data (in number of systems) was converted to average capacity based on a review of current Australian market data.[8] **2. Future installation scenario:** Installation data for virtual power plant and behind the meter batteries is from the AEMO 'Step Change' Scenario (2020 ISP).[9] **3. Average:** Average lifespans of 10 and 12 years were based on a review of literature and expert interviews. Current product warranties are generally 10 years. However, as batteries are a comparatively new technology, there is little data available on lifespans. **4. Average weight:** Battery weight is based on a review of current Australian market data.[10] This weight is kept constant across the time period, however there may be improvements in efficiency which reduce battery weight in the future. The shape parameter for the Weibull function (that defines the spread of when panels reach end of life) is assumed as 3.5 as there is no data available on energy storage batteries. **5. Battery types:** The share of battery chemistries is estimated based on current market share.[11] It is estimated that LIB are approximately 90% of all energy storage batteries, with 5% lead acid and 5% other types (such as flow batteries). Because there is significant uncertainty for the technology types that may emerge as important in future, is assumed in these projections that this share remains constant over the time period. We note that LAB were previously the dominant technology but at this point the market was very small and hence the waste volumes are also very small.

Summary Findings

PV Panels

1. PV waste generation in NSW is currently low (less than 2,000 tonnes per year), but could reach 3,000 – 10,000 tonnes per year by 2025 and 34,000 – 63,000 tonnes per year by 2035

The volumes of PV waste are highly dependent on average lifespan used in the projection. For example, by 2035 there is projected to be nearly double the volumes of PV waste generated if PV panels are assumed to have a 15-year lifespan, compared to a 20-year lifespan. The average life of PV panels in Australia is not known, and there is a paucity of data on early losses, so there could be higher volumes of waste in the short term than projected in this study.

2. Distributed systems are responsible for almost all waste in the early years (~ 88% in 2025), but by 2035 both utility and distributed installations create a large share of waste

In 2025 approximately 88% of PV waste is from distributed systems. This is because most of the early installations of PV in NSW have been distributed (behind-the-meter residential and commercial / industrial systems), and in 2019 there is twice as much distributed than utility scale PV capacity. However, utility scale capacity is projected to grow and by 2025, the waste from utility scale solar increases so that distributed systems are ~ 60% of waste and utility scale ~ 40%. Utility scale solar farms and distributed systems are projected to a similar capacity in future installations.

3. PV panel waste is likely to arise initially in Sydney, the Central Coast and Northern Coastal Regions

An assessment of the geographical distribution of the early installations indicates where early volumes will arise.

Batteries

1. Energy storage battery waste generation remains low by 2025 (< 1,000 tonnes per year), but could reach 6,500 – 8,200 tonnes per year by 2035

Waste from energy storage batteries remains low in the short term, as batteries have only been installed in NSW within the last 5 years and in small numbers. Over the time period of this study battery waste is much lower than PV waste. However, battery waste is projected to grow at a faster rate than PV waste, with waste volumes 13 times higher in 2035 compared to 2025 (assuming a 10-year lifespan).

2. Virtual power plant (VPP) batteries are responsible for ~30 – 35% more waste per year than distributed (behind-the-meter) battery systems in 2035

There is significant uncertainty in the volumes and locations of battery waste. In the AEMO scenarios used for this projection, it is assumed there will be more batteries installed as part of virtual power plants than behind the meter in the period until 2035. This scenario also assumes that pumped hydro will provide more storage than batteries in NSW. However, if batteries are used instead of pumped hydro, there may be larger volumes of battery waste in future than the projections in this study.

3. LIB are assumed to be 90% of installed batteries (in MW) and 75% of waste (in tonnes)

LIB are assumed to be 90% of energy storage batteries by capacity (MW), based on current market share. However, as lead-acid and other types of batteries (such as flow batteries) are heavier per MW, LIB are only 75% of waste by weight.

Key Stakeholder Insights

Factor	Description
1: EARLY PV PANEL LOSSES	The lifetime of some PV panels may be shorter than the 25-year performance warranty due to: • Low quality PV panels entering the market (could be up to 80% of rooftop according to several stakeholders) • Financial incentives to decommission rooftop systems before end of life Installation locations and the pairing of PV panels with different capacities is causing early system failures.
2: BATTERY CHEMISTRIES	The composition of waste batteries will be dominated by LIB (assumed to be ~ 90 % of systems).
3: BATTERY STORAGE FOR ROOFTOP	About 10% of rooftop PV systems have storage in NSW.

PV Panel Waste Generation

The following figures show estimated volumes of PV panel waste in NSW to 2035. The graphs compare an assumed 15 and 20 year lifespan. While many PV panels have a 20 year performance warranty, stakeholder insights suggest that early losses may reduce the average to 15 years.

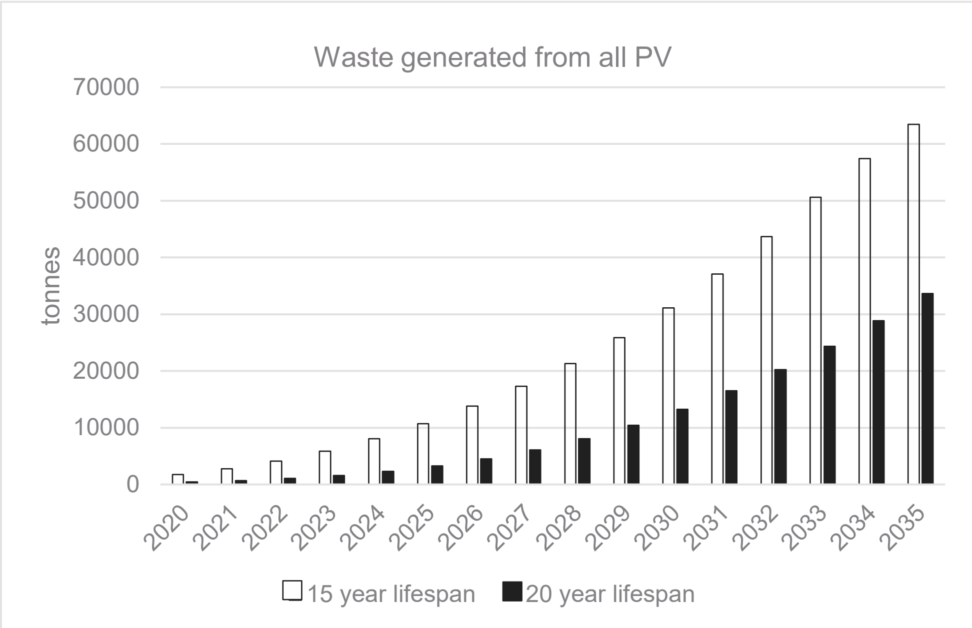


Figure 1: estimated waste volumes for all End of Life (EOL) PV panels (tonnes)

Figure 1 suggests that PV waste generation in NSW is currently low, but could reach ~3–10 kt per year by 2025 and 34–63kt per year by 2035.

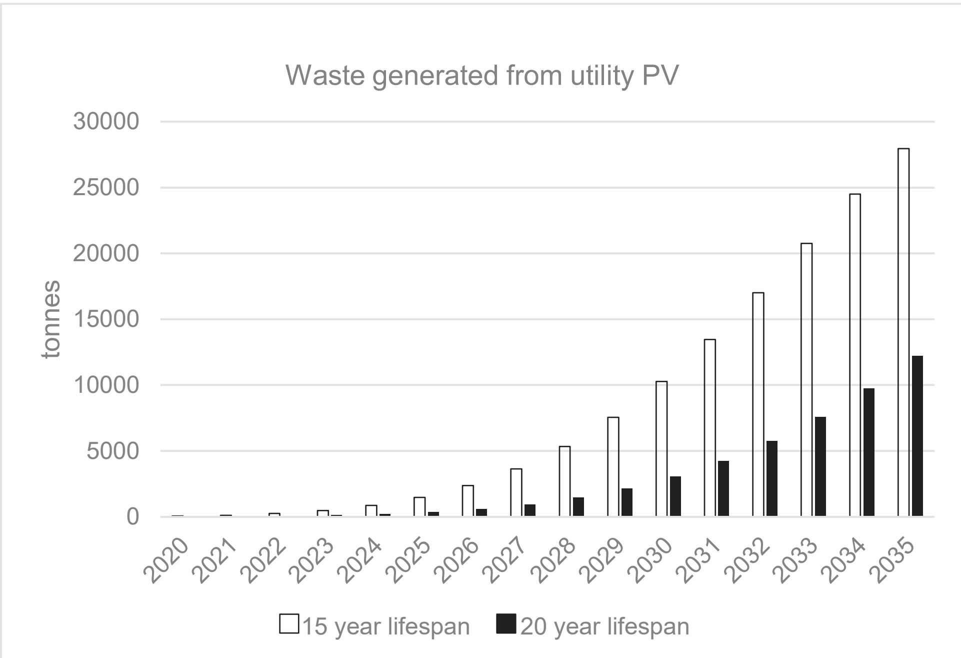


Figure 2: Waste generated from utility PV

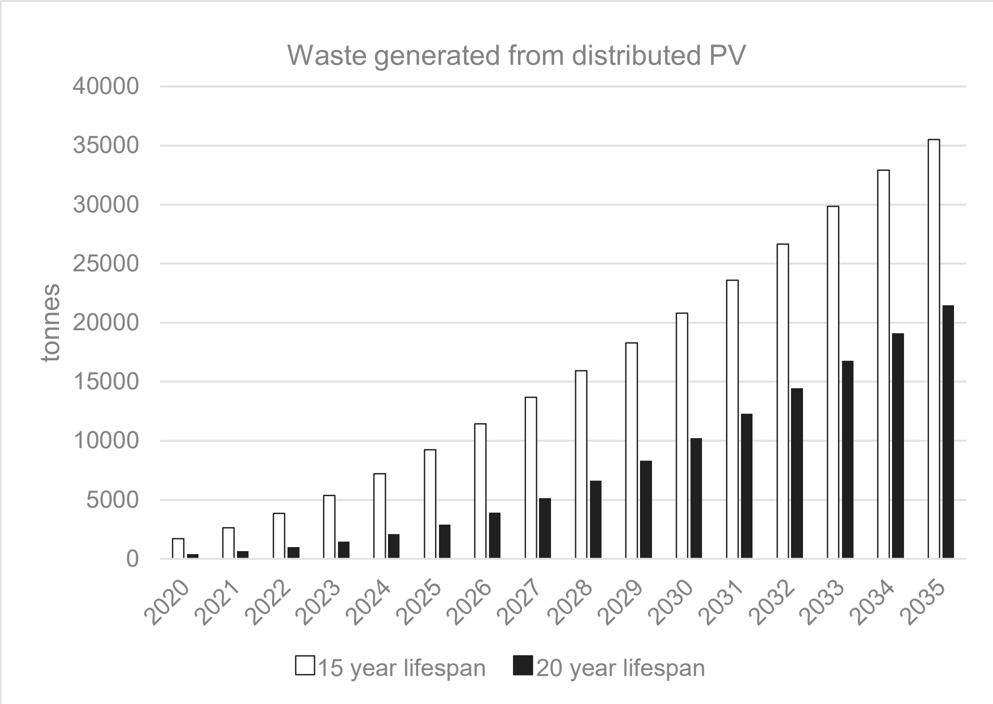


Figure 3: Waste generated from distributed PV

Figures 2 & 3 show estimated waste volumes for EOL PV panels (tonnes); Figure 2 shows waste volumes associated with utility systems and Figure 3 shows waste volumes associated with distributed PV systems. They also highlight that distributed PV systems are responsible for almost all waste in the early years (~ 88% in 2025), but by 2035 both utility and distributed installations create a large share of waste.

Battery Waste Generation

The figures in this section show estimated volumes of battery waste in NSW to 2035. The graphs compare estimated volumes assuming a 10 and 12 year lifespan.

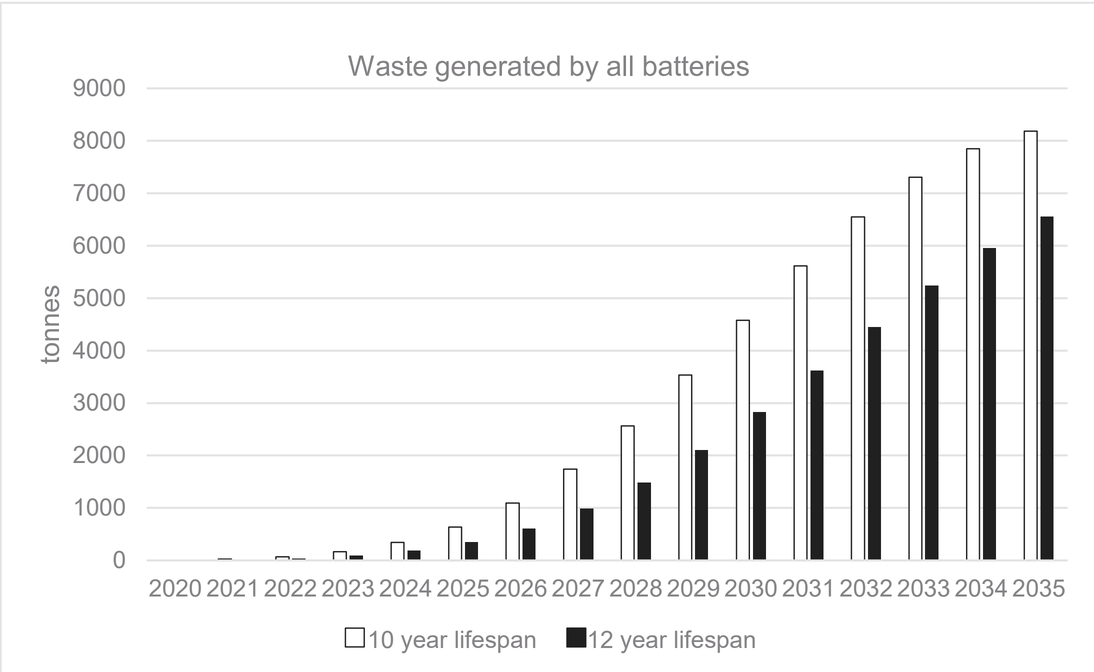


Figure 4: estimated waste volumes for all EOL batteries (tonnes)

Figure 4 suggests energy storage battery waste generation remains low by 2025 (< 1,000 tonnes per year), but could reach 6,500–8,200 tonnes per year by 2035.

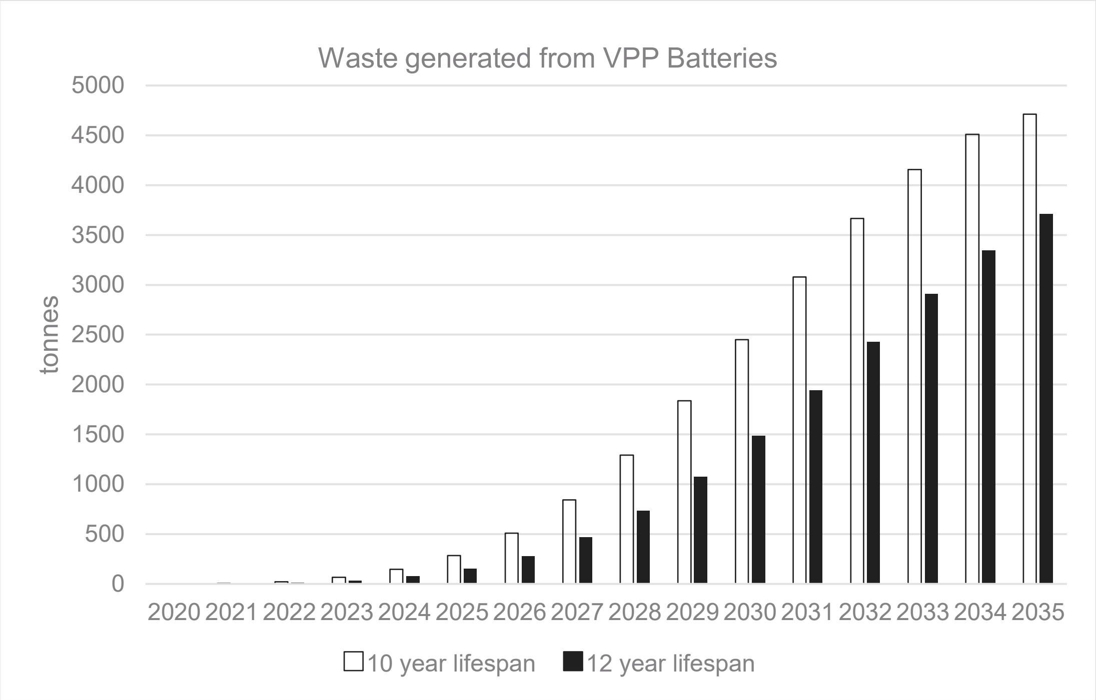


Figure 5: Waste generated from VPP batteries

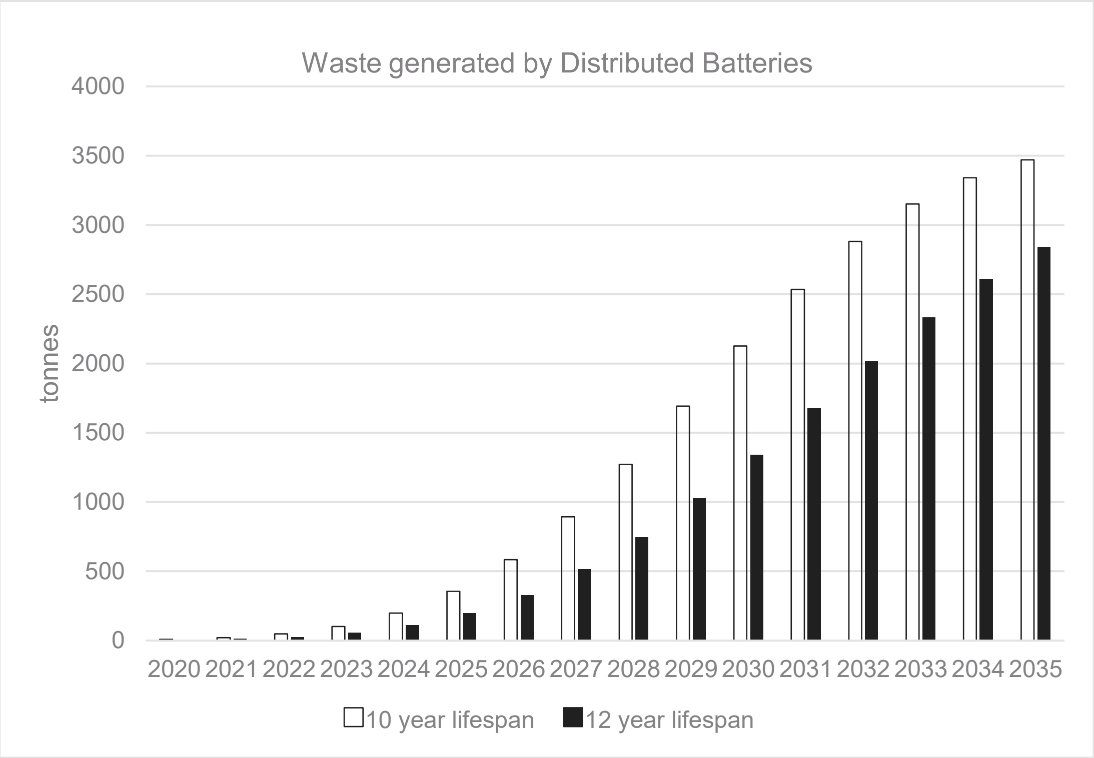


Figure 6: Waste generated from distributed batteries

The Figures 5 & 6 show estimated waste volumes for EOL batteries (tonnes); Figure 5 shows waste volumes associated with VPP systems and Figure 6 shows waste volumes associated with distributed systems (behind the meter). They also suggest that virtual power plant (VPP) batteries are responsible for ~30–35% more waste per year than distributed (behind-the-meter) battery systems in 2035.

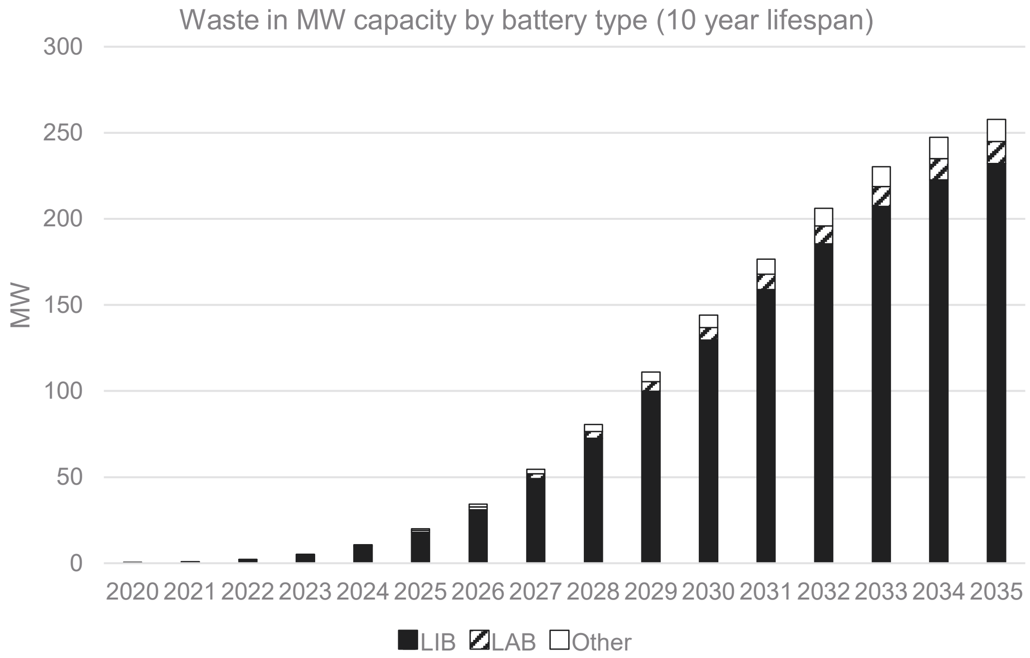


Figure 7: Waste in MW capacity by battery type (10 year lifespan)

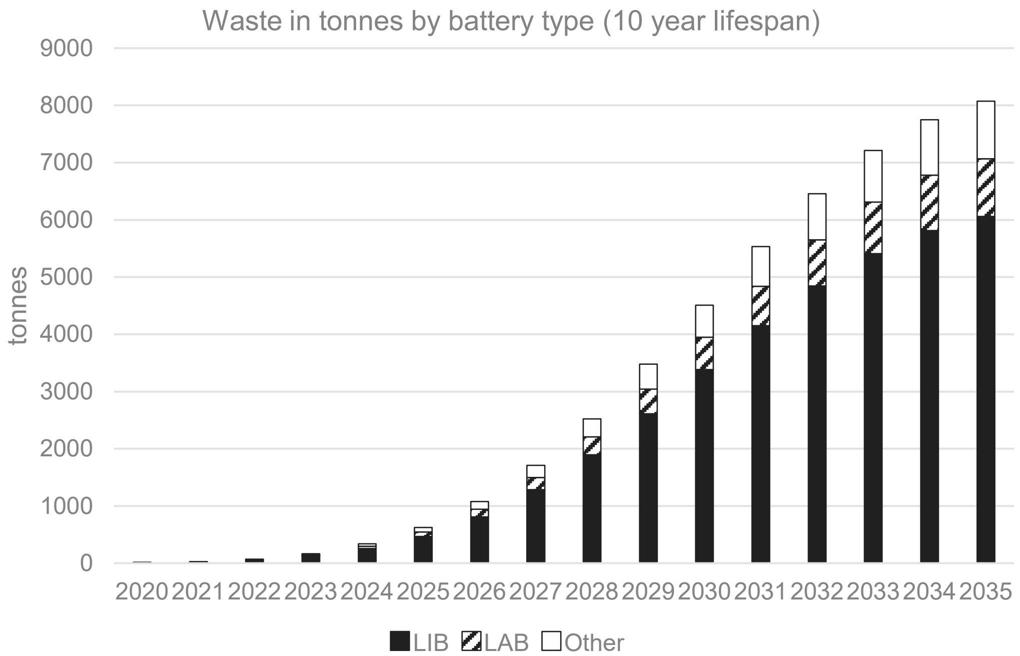


Figure 8: Waste in tonnes by battery type (10 year lifespan)

In Figures 7 & 8 LIB are assumed to be 90% of installed batteries (in MW) and 75% of waste (in tonnes). We note that LAB were previously the dominant technology for energy storage however the market for energy storage was very small at this time, so expected waste volumes are also small.

Regional Breakdown of PV Installations

The historical data on PV installations has been mapped by Local Government Areas (LGA), in order to understand where PV waste volumes are likely to arise (see[1–4] for sources). The following maps show distributed and utility scale system installations by LGA in NSW and ACT in 2019, 2015 and 2010.

These maps can be used to estimate where waste is likely to arise. For example in the period of 2025-30, waste is likely to arise in areas with installations before 2010. The results of the regional breakdown of solar installations have a number of implications for the management of future waste generation, including:

1. PV panel waste will likely arise initially in Sydney, the Central Coast and Northern Coastal Regions owing to the early uptake in these areas.
2. Installations in 2010 are only from small-scale distributed systems, with the highest rates of installation in Blacktown, Central Coast and Lake Macquarie. These lgas also consistently have the highest rates of installation for distributed systems from 2015 to 2019.
3. Three utility scale systems are installed by 2015 in Bogan, Broken Hill and Queanbeyan and one in the ACT. The number of utility systems increased to 22 by 2019 with the largest systems located in Murrumbidgee and Dubbo.
4. The highest total installed capacity (distributed and utility) in 2019 is in Murrumbidgee and Dubbo owing to the utility systems while Blacktown remains in the top three lgas. The installed capacity in Blacktown increased by more than a factor of 10 from 2010 to 2019.

Total installed PV capacity by LGA in 2019

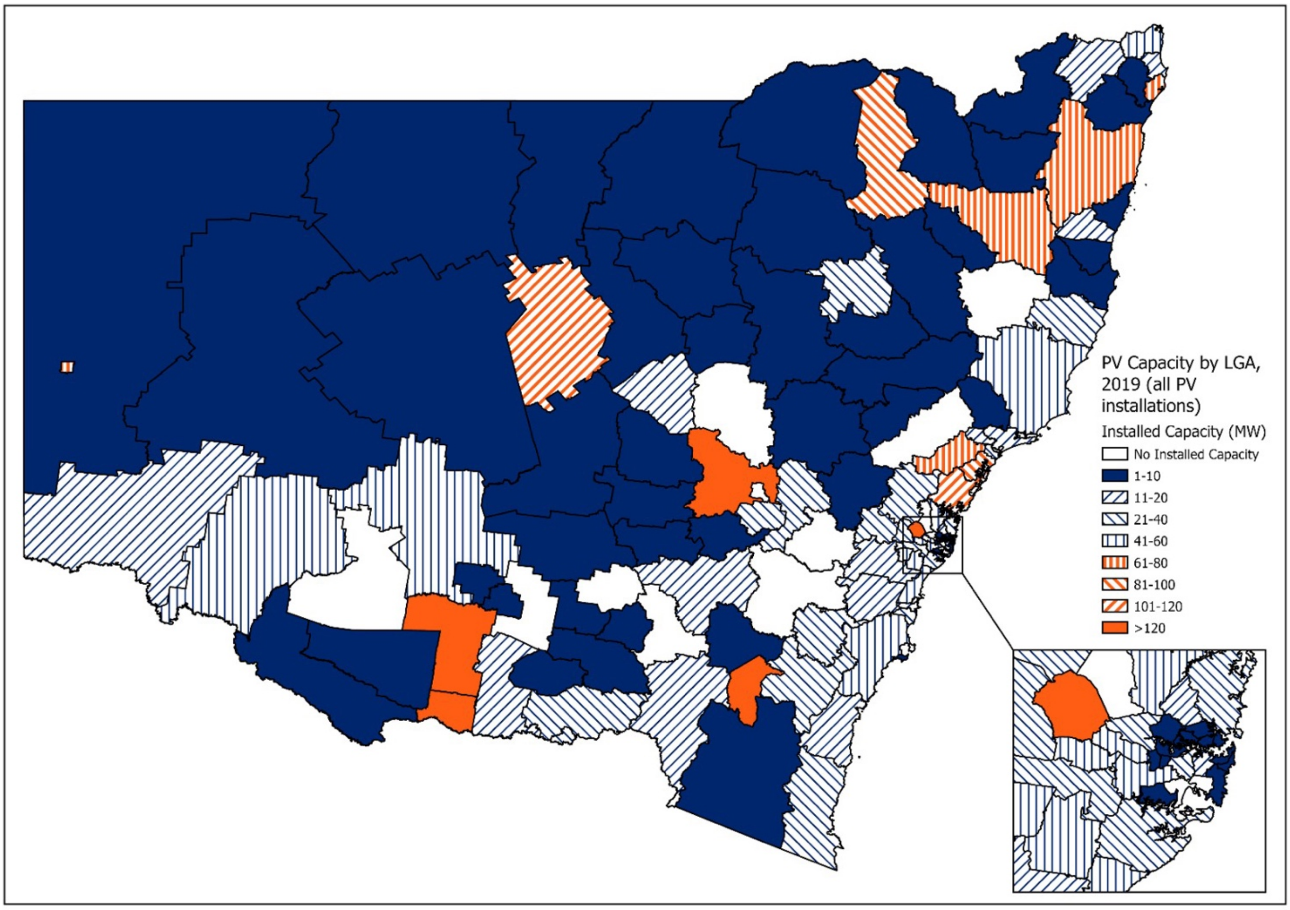


Figure 9: Map of PV capacity by LGA 2019

Figure 9 shows total installed capacity in NSW in 2019 by LGA. The LGAs with the highest capacity are Berrigan (Riverina area) Murrumbidgee, Dubbo and ACT owing to utility scale installations (the data set includes 22 utility scale systems). LGAs around Sydney, Central Coast and Central West NSW also have very high installed capacity.

Total installed PV capacity by LGA in 2015

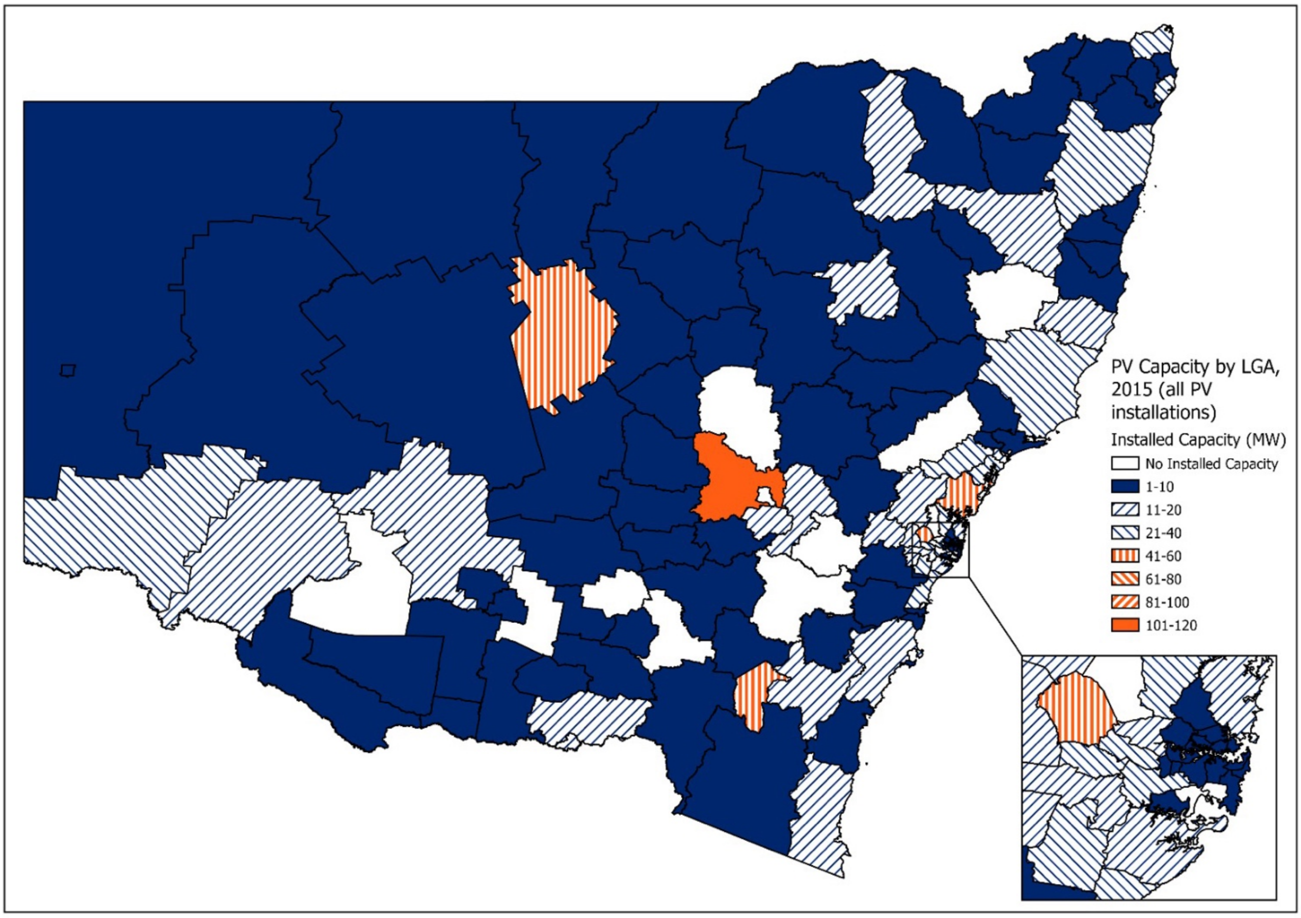


Figure 10: Map of PV capacity by LGA 2015

Figure 10 shows total installed capacity in NSW in 2015 by LGA. The LGAs with the highest capacity from utility scale installations are Cabonne, Bogan and the ACT (the data set includes 4 utility scale systems). LGAs in and around Sydney (Blacktown, Central Coast, Lake Macquarie and Hornsby) and the north coast (Ballina, Tweed) have very high installed capacity for small-scale distributed systems.

Total installed PV capacity by LGA in 2010

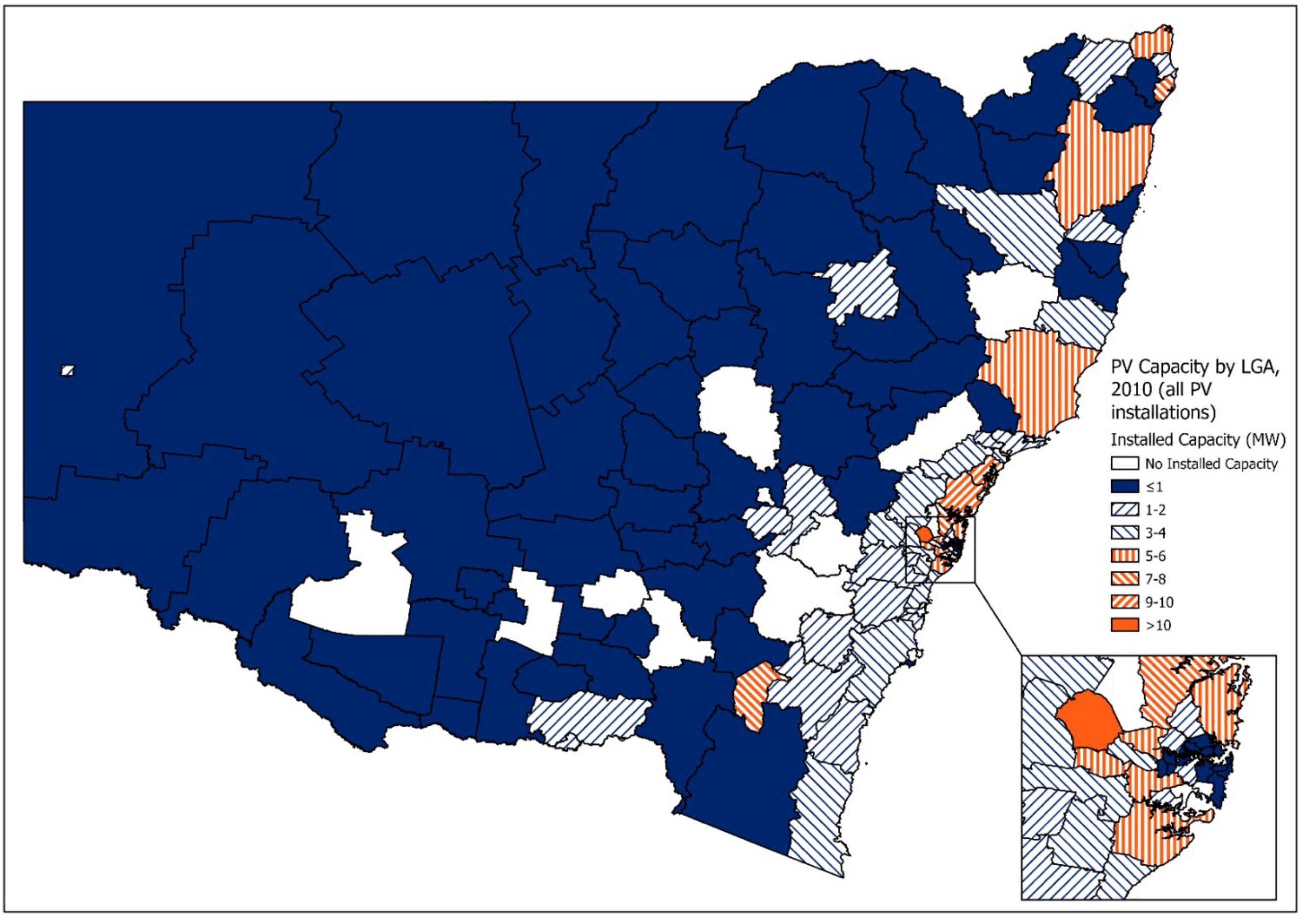


Figure 11: Map of PV capacity by LGA 2010

Figure 11 shows total installed capacity in NSW in 2010 by LGA. Installations in 2010 are small-scale distributed systems only with the highest rates of installation in Blacktown, Central Coast and Lake Macquarie.

Implications of Findings

Waste from PV and battery storage systems is currently low but is projected to grow significantly in the next decade. PV waste reaches significant volumes of 3,000 to 10,000 tonnes per year by 2025, while battery waste remains low in this period (< 1000 tonnes). In 2025 PV waste is projected to be 9 to 16 times greater than battery waste (depending on the average lifespan).

Battery waste grows at a faster rate than PV owing to the shorter lifespan of batteries compared to PV panels, However PV panels will remain a greater source of waste, with PV waste projected to be 5 to 8 times greater than battery waste. By 2035 PV waste could reach 34,000 – 63,000 tonnes per year and battery waste 6,500 – 8,200 tonnes per year.

Phase 1 highlights that waste from distributed PV panels (particularly concentrated in Sydney, the Central Coast and Northern Coastal Regions) is the most immediate concern considering the volumes of waste to be managed. However, systems to manage battery waste will need to scale up rapidly later in the period.

Further Research Required

Further research is required to determine the extent of early losses of PV panels, including poor quality PV panels, early decommissioning due to single PV panel failure, and poor installation and maintenance. Part of this research would require sample testing of currently installed rooftop PV system efficiency.

Phase 1 References

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8. Solar Battery Storage Comparison Table. Available at: https://www.solarquotes.com.au/battery-storage/comparison-table/. (Accessed: 2 December 2019).

9. AEMO (2019) Draft 2020 Integrated System Plan (ISP) [Step Change scenario]. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan/2019-Integrated-System-Plan. (Accessed: 18 December 2019).

10. Solar Battery Storage Comparison Table. Available at: https://www.solarquotes.com.au/battery-storage/comparison-table/. (Accessed: 2 December 2019).

11. Ibid

Phase 2 – Technology Assessment

Objectives

Identify and provide detailed case studies on the most promising reference processes and facilities from Australia and overseas for collection, reuse and recycling of PV panels and batteries that could become options for an industry in NSW. This review focuses on c-Si PV panels and LIB as these technologies have the largest market share.

Approach

Drawing on the literature that describes the different technologies and provides data on technology maturity, materials recovered, advantages and disadvantages, as well as stakeholder engagement, we assessed the most appropriate types of collection, reuse and recycling for NSW for both PV panels and batteries. We also identified any further research, development or demonstration that may be required.

The primary literature that informed this assessment was sourced from academic journals, reports, conference presentations and online.[1-7]

Stakeholder interviews with industry were conducted to gauge the tech-readiness of different recycling pathways, the logistics and costs associated with different options, and barriers and opportunities not covered in the published literature.

This assessment informs Phases 3, 4, 5, and 6.

Summary Findings

PV Panels

1. Low recovery (downcycling) is a relatively established and simple method demonstrated overseas, but it carries a risk and lost opportunity in terms of high value material recovery.

'Low recovery' or downcycling refers to processes that can recover material from discarded PV panels that may not be of a suitable purity for remanufacturing new PV panels. These pathways use crude processing techniques, primarily crushing and shredding, to recover the frame and crushed glass that may be suitable for lower value applications such as road base. This pathway is the only pathway that is demonstrated at commercial scale and can potentially divert ~80 % of the material from landfill (frames, glass, junction box) with relatively low energy input and processing costs. A significant processing risk is the production of a contaminated residual stream (see footnotes 8 & 9), requiring further treatment or disposal.

2. High recovery involves delamination (of the adhesive encapsulation layer) that can be achieved through mechanical, thermal or chemical methods.

The major benefit of the high material recovery is the potential to obtain intact silicon wafers and metals. These processes remain at the pilot or pre-commercial development phase. The amount of recyclable material that may be recovered is reported to be greater than 90%.[10]

3. Chemical treatments for delamination and metal extraction pose a challenge.

Chemical delamination can be achieved using inorganic or organic solvents that produces a liquid waste stream that requires appropriate treatment and disposal.[11]

Key takeaway Message

Further R&D is required to develop advanced processes for high value recovery and managing / avoiding contaminated residual streams from low recovery pathways. Establishing collection systems is also a priority for any recovery pathway.

Batteries

1. LIB recycling technologies are relatively mature, however there is an opportunity for further optimisation for achieving a closed-loop battery system. A market for LIB reuse is being developed mainly targeting the reuse of EV batteries for stationary applications.[12]

LIB recycling involves a combination of mechanical and/or thermal pre-treatment steps, pyro- and/or hydrometallurgical processing that are mature processing technologies developed for e-waste processing as well as the recycling of discarded LIB from other applications, e.g. Consumer electronic.[13]

2. 'Initial processing' involves discharge, disassembly and shredding/crushing to produce a mixed metal dust ('black mass') consisting of Li, Co, Ni, other minor metals and graphite representing ~35 % of the discarded battery stream.[14]

One company in Australia is currently performing this initial processing step and exporting the black mass for downstream processing. Scrap metal (Al, steel, Cu) can also be recovered at this step.

3. 'High recovery' or full-chain recycling can achieve a total material recovery of ~60 %, including Li (lico3), Co (hydroxide), Ni (hydroxide), Fe, Cu and Al (scrap); Material losses include the solvent, plastics and minor metals.[15]

Materials can be recovered at suitable purities for cathode manufacturing (or other applications).

Key takeaway Message

Battery recycling technologies are relatively mature. Several different process routes exist at industrial scales overseas.

Key Stakeholder Insights

Factor	Description
1: E-WASTE PROCESSING TECHNOLOGY	• Many PV panel and battery 'recycling' operations in Australia are utilising technology developed for e-waste processing which are not optimised for closed-loop PV panel or battery systems • These systems are the most technically advanced and can achieve significant recovery by volume (i.e. Recovery of the Al frames and glass), but further R&D is required to enable higher value recovery of silicon and metals
2: INNOVATIVE PROCESSING TECHNOLOGY	• More innovative pathways that can recover intact silicon wafers or electrode powders for reuse, represent the highest value recovery • R&D for advancing processing methods at the 'proof of concept' stage lacks secure funding
3: LOGISTICS (PV PANELS)	• Transporting PV panels is currently expensive, particularly if PV panels need to be kept intact.
4: LOGISTICS (BATTERIES)	• Processing technology development may not be as challenging as addressing front-end logistics • It is difficult to move batteries across state borders due to current dangerous goods regulations, unless some pre-processing has occurred.

PV Recycling Process Overview

Figure 12 provides an overview of the different pathways for recycling PV panels. This section summarises and compares these pathways.

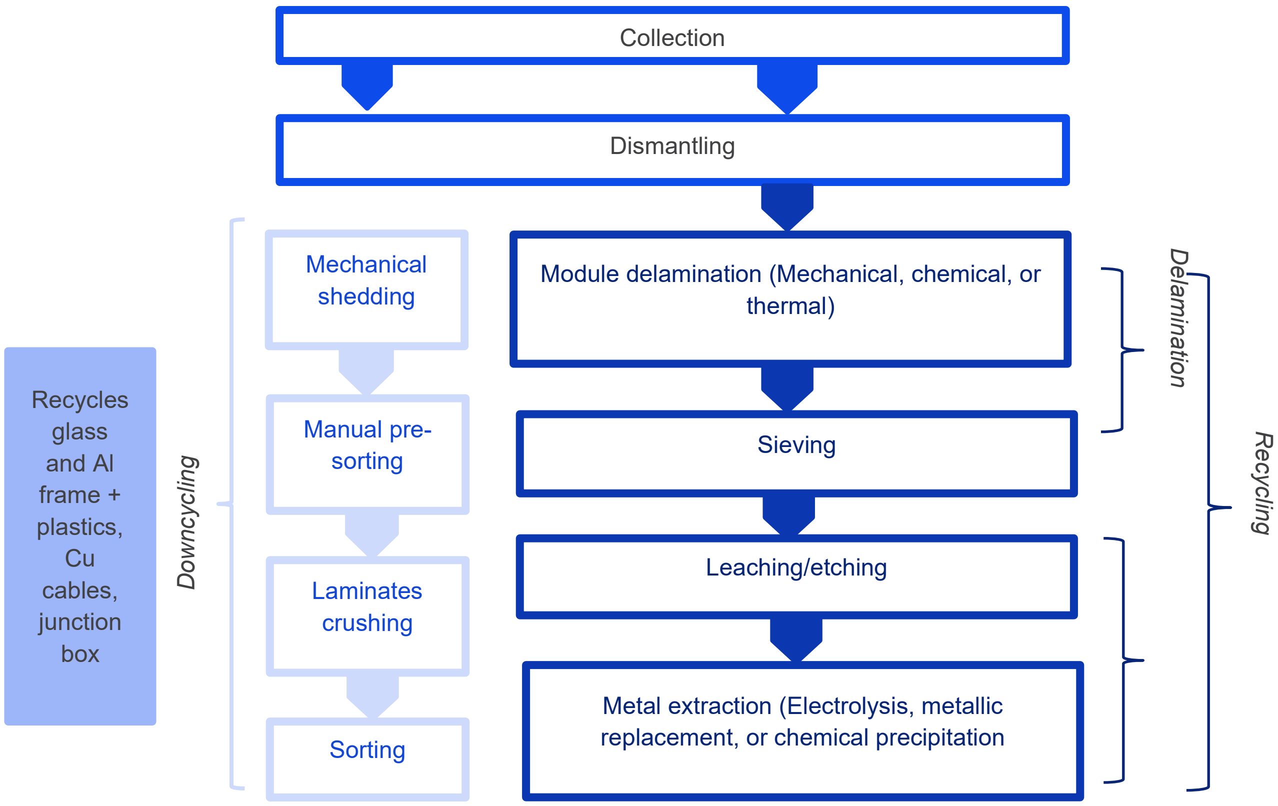


Figure 12: PV recycling process overview[1]

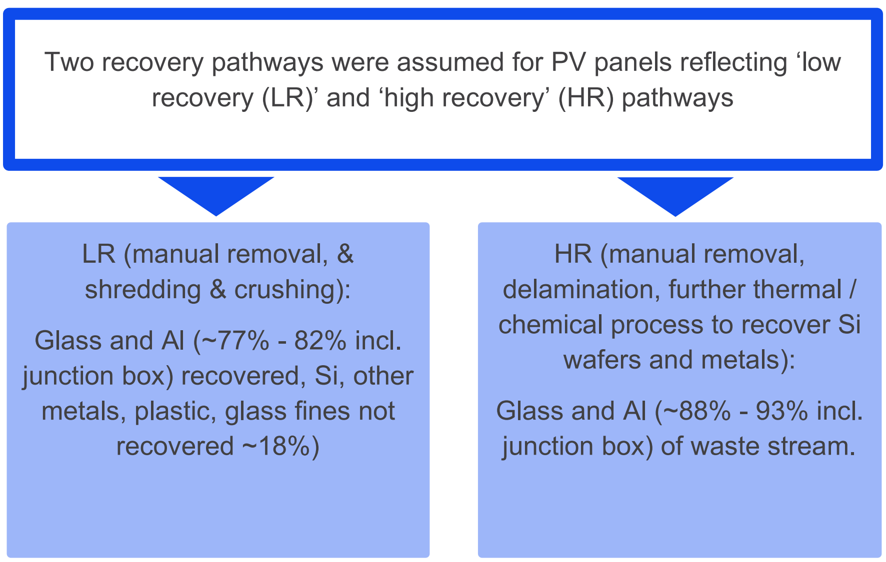


Figure 12 provides an overview of the different processes for PV recycling. All of the pathways involve collection and dismantling to separate the junction box and the Al frame. The ‘low recovery’ or downcycling pathway (shown in black on the left-hand side) involves crushing and shredding and recovers glass and the Al frames, Cu cables and the junction box. ‘High recovery’ recycling pathway involves module delamination enabling the recovery of Si wafers and metals. These processes are described in further detail below.

The range of processes reviewed are at varying levels of technical maturity. In the following section we categorise the different processes according to their technical maturity. A three-level code is assigned: blue indicates processes that remain at the early R&D phase (laboratory-scale), black indicates more advanced technology development at the pilot scale, and green indicates the most mature technologies demonstrated at commercial scales.

The following colour key is used to designate the level of technological maturity:

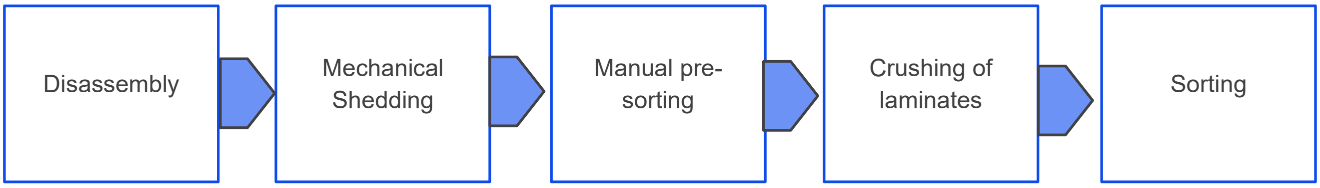
Research Pilot/pre-commercial Commercial

Method	Summary	Maturity
Downcycling	This simple recycling method avoids most masses to be landfilled with relatively low energy input and processing costs. However, the process risk means that there is a chance that a significant amount of the waste may be contaminated. This contaminated waste ultimately ends up in landfill meaning smaller volumes being recycled than expected.	Commercial (green)

How it works / principles

The downcycling approach recycles module glass and Al frame, which has been demonstrated in Europe. Since glass constitutes more than 75%w of a module, glass recyclers tried to shred these modules in existing flat-glass recycling line.

End of life process for crystalline silicon modules (Downcycling)



Disassembly: Manual removal of the relay box and stripping it of its components, removal of Al frame.

Shredding: Shredding and milling is a pre-processing step.

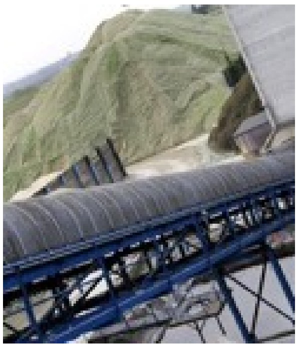
Manual pre-sorting: Materials sorted manually for extracting glass and Al for recycling

Crushing of laminates: Crushing of laminate material.

Sorting: Further sorting of materials, with the ferrous metal sent to specific recyclers and the mix that can’t be separated further sent to landfill.

Example: Belgium Maltha Glass recycling

This process firstly manually removed the Al frame, junction box and Cu cables. Then the module was shredded on the glass recycling line, followed by crushing and a series of manual and mechanical sorting and extraction processes to recycle most of the glass and Al.



Module delamination: Mechanical

- Delamination through mechanical means can be done several different ways, involving mechanical detachment of the glass and other materials from the module. Some of the processes involve some form of additional treatment, e.g thermal or chemical; a dedicated and highly automated PV recycling facility in France (Veolia Rousset) separates glass (> 60 % as clean cullet), Al, Cu cables and Si that are provided to the metals sector and a recovery rate of 95 % is reported.

Technology	Description	Maturity	Materials recovered, residuals	Advantages	Disadvantages
Shredding / milling (Veolia Rousset)	Shredding, cutting, milling		Glass cullet (80-85%w of the module), Si (and other metals) that need extra treatment to achieve > 90 %	Can be implemented based on existing recycling infrastructure for high throughput The most sophisticated systems use robotics Low energy/chemical consumption Suitable for mobile processing	Additional thermal and chemical processes needed
Cryogenic (Yingli Solar)	Cooling (-196ºc) then abrasive grinding to peel Si powders from plastic powders.		Si, plastic powders, glass cullet (recycling yield unclear).	Si is recoverable Low chemical consumption	Likely high energy consumption (cost/emission implications) but immature process needing further research
Hydro-thermal (Trina Solar)	Detaches glass from module under oxidant hydrothermal subcritical conditions		Si, plastic powders, glass cullet (recycling yield unclear).	Si is recoverable	Likely high energy consumption (cost/emission implications) but immature process needing further research
Hot knife cutting **(e.g 'FRELP Process'/ PV Cycle Italy)**	Cuts apart entire module glass sheet using high frequency knife at elevated temperature.		Glass (98%w of the module). EVA/solar cell/ backsheet sandwiches sent to incineration plant for further treatment.	Avoids multiple crushing and thermal treatments by detaching glass in a single step. High % of glass recovery Concept shown to work with different types of cutting method Able to recover intact components with higher reuse value. Low energy/chemical consumption	Low throughput Slow process

Module delamination: Thermal

This form of delamination involves separating the modules through thermal decomposing of the encapsulation layer between the glass and the solar cells. The benefits of these methods are their capability in obtaining unbroken solar cells and high purity silicon wafers.

Technology	Description	Maturity	Materials recovered, residuals	Advantages	Disadvantages
Pyrolysis (Solar Cells Inc., Deutsche Solar, Solarworld)	Pyrolysis of the polymeric encapsulation layer (mostly EVA) at high temperatures under an inert gas environment	●	Intact/broken glass sheet, solar cells, Cu ribbons, Al framing, various combustible oils and gasses (including acetic acid, propane, propene, ethane, methane).	Breaking/cracking issue solvable with different tools/treatments Optimised process could recover nearly 100% of tempered glass and high purity solar grade Si. Higher reuse value - Delaminated solar cells can be manufactured into new modules and serve a second life Cost effective industrial recycling process	• Wafers can break or crack during the thermal process • Low throughput • High energy / chemical consumption (cost/emission implications) • Loss of materials that are completely combusted
Combustion of EVA	Combustion of the polymeric encapsulation layer (mostly EVA and backsheet) under an oxygen rich environment to provide energy for heating furnace.	●	Intact/broken glass sheet, solar cells, Cu ribbons, Al framing.		• Low throughput • High energy / chemical consumption • Can result in harmful emissions that require treatment • Loss of materials that are completely combusted

Module delamination: Chemical

Chemical delamination of the adhesive encapsulation layer in inorganic or organic solvents.

May require additional treatments to speed up or to complete process.

The liquid waste stream also poses a challenge in managing the solvents required to dissolve the polymeric binders.

Technology	Description	Maturity	Materials recovered, residuals	Advantages	Disadvantages
Inorganic solution (e.g Korea Electronics Technology Institute)	Solar glass separated from solar cells by immersing module in an inorganic solution for 1-2 days.		Solar cells, solar glass	• Easy access to the EVA • Less cell damage • Recovery of glass • Ultrasonic radiation has been shown to reduce reaction time to 30 minutes to recover damage free solar cells	• Very low throughput • Very high energy/chemical consumption (cost/emission implications) • Finding an effective solvent that requires no further manual separation. • Harmful emissions and waste
Organic solutions (e.g Tokyo University of Agriculture and Technology)	Dissolution of EVA in organic solutions with acceleration of process possible through applying ultrasonic radiation.		Solar cells, solar glass	Ultrasonic treatment speeds up process Less cell damage Recovery of glass Easy access to EVA	Without applying ultrasonic radiation the process can take 10 days. Expensive equipment Sometimes a secondary treatment using pyrolysis is needed when organic solvents aren't able to remove EVA. Very low throughput Very high energy/chemical consumption (cost/emission implications)

Metal extraction

Metal can be extracted and purified from the leaching solution.

The approaches are commonly deployed by the hydrometallurgical industry.

Technology	Description	Maturity	Materials recovered, residuals	Advantages	Disadvantages
Chemical precipitation	Separating metal compounds using a solvent	●	Ag (89.7%), Pb	Removes hazardous elements such as Pb from the waste Complete removal of EVA and metal coating on wafer Can recover intact cells	Can cause defects due to inorganic acid Harmful emissions and wastes

Battery Recycling Process Overview

Figure 13 provides an overview of the different pathways for recycling batteries linked to PV systems. This section summarises and compares these pathways.

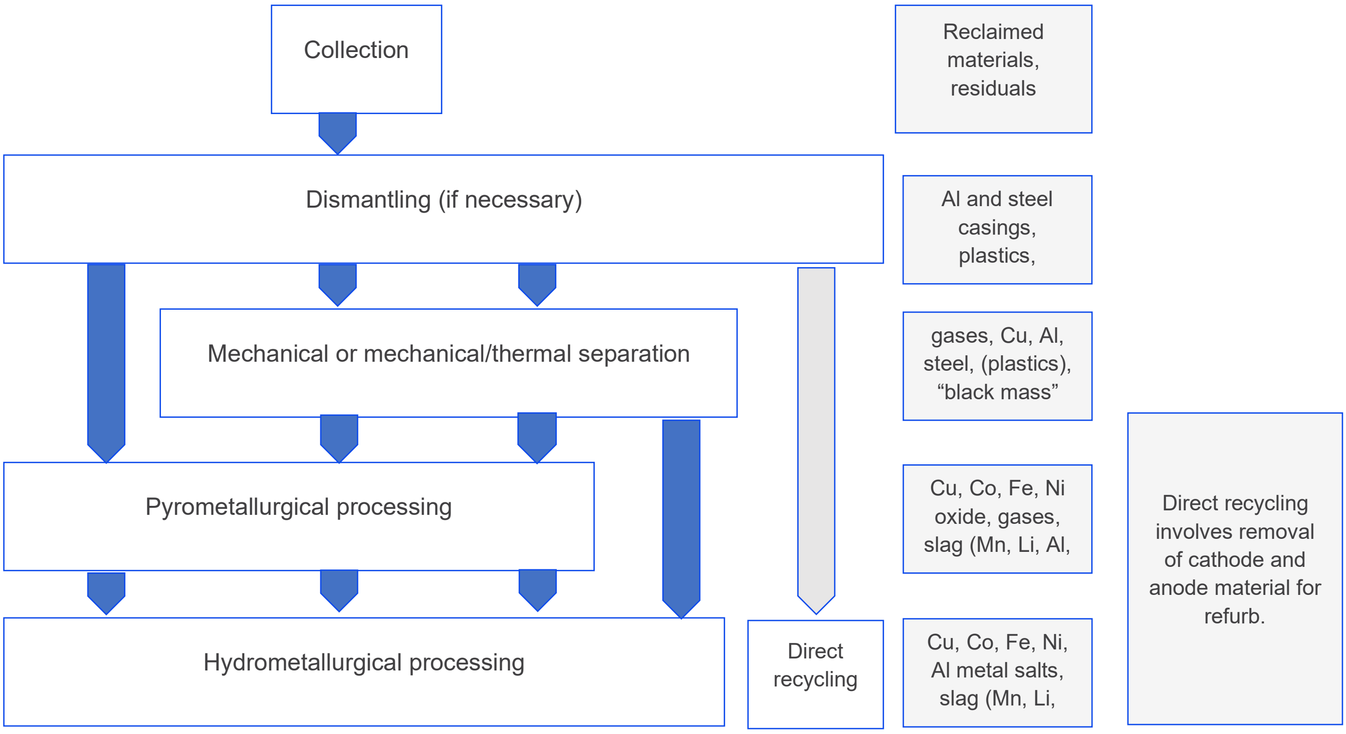


Figure 13: Battery recycling process overview

Figure 13 provides an overview of the different processes for LIB recycling. All of the pathways involve collection and dismantling followed by mechanical and/or thermal pre-processing and pyrometallurgical and/or hydrometallurgical processing. Different materials may be reclaimed at the different steps shown on the right-hand side with a recovery rate of 25-60% depending on the recovery pathway. The figure also shows direct recycling (in grey) that aims to recover the cathodes and anode materials for refurbishment. These processes are described in further detail below.

The range of processes reviewed are at varying levels of technical maturity. In the following section we categorise the different processes according to their technical maturity. A three-level code is assigned: blue indicates processes that remain at the early R&D phase (laboratory-scale), black indicates more advanced technology development at the pilot scale, and green indicates the most mature technologies demonstrated at commercial scales.

Summary

- LIB recycling technologies are relatively mature, however there is an opportunity for further optimisation for achieving a closed-loop battery system
- Several different process routes exist at industrial scales overseas
- Materials can be recovered at suitable purities for cathode manufacturing (or other applications

Comparison of battery recycling technologies and their maturity

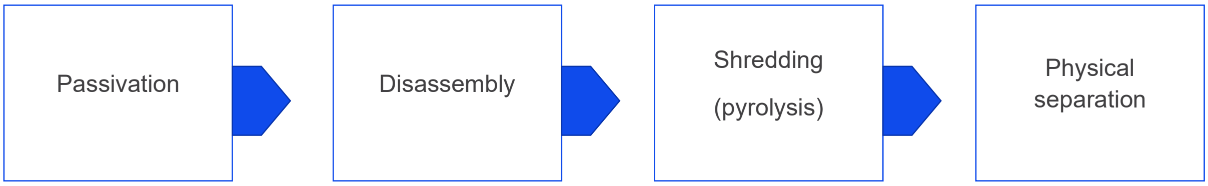
Technology	Description	Maturity	Materials recovered, residuals	Advantages	Disadvantages
Pre-process	Passivation, disassembly, physical separation (mechanical and/or mechanical and thermal)		Al, Cu, steel are reclaimed, (plastic), 'black mass' (Co, Ni, Li, Mn and carbon)	• Avoids stockpiling (disposal to landfill) • Scrap metal and plastics recovered for (local) manufacturing • Pre-processing improves efficiency of downstream metals recovery (hydro)	• Changes in LIB chemistry may undermine economic viability • Significant loss of embedded value in manufactured cathode • Manual disassembly presents risk to human health and is costly, automated disassembly could reduce risk and improve economics
Pyro (e.g Xstrata Nickel)	High temperatures used to reduce component metal to alloys of Co, Cu, Fe and Ni, established commercially for consumer LIB		Metal alloy containing Co, Cu, Fe and Ni (that can be separated by hydro), slag containing Al, Mn, Li (can be reclaimed or used in cement industry), gases generated by decomp. Of electrolyte and binders	• Robust process suited to imperfect feedstock (batteries can be processed with other waste) • Minimal pre-processing required • Hazards are contained in process (high-temp decomposes electrolyte, binders)	• High capital costs • Limited recovery of materials, electrolyte (40-50% by mass) not recovered, post processing required to recover Li, Mn salts • High energy requirements (offset by exo. Decomp. Of electrolyte and plastic) • Produces toxic gases that must be captured or remediated
Hydro (e.g Recupyl)	Aqueous solution used to leach out metals from the cathode material, recovered by precipitation		Co is extracted as the sulphate, oxalate, hydroxide or carbonate, other metal salts e.g. Li, waste water (aft. Neutralisation of solvent)	Materials can be recovered at suitable purity for cathode materials (or other applications)	• Large volumes of solvent required (H2SO4/H2O2) • High costs of neutralising the solvent • Significant pre-processing required (often manual, implies cost at scale) • Research focussed on reclamation of metals in concentration required for cathode chemistries/'bioleaching'
Direct recycling	Removal of cathode or anode material from electrode for reconditioning		Most work has focused on reclaiming the cathode material, some limited focus on recovery of graphite (anode)	Embedded value in manufactured LIB is retained Advantageous for lower value cathode oxides;	• Process needs to be tailored for specific chemistries • Sensitive to contamination (limiting pre-processing and removal of polymeric electrode binder problematic)

Initial processing case study

Method	Summary	Maturity
Initial processing	According to the Australian Battery Recycling Initiative, there are nine LIB battery “recyclers” in Australia and most collect and export overseas, all active in NSW One company (Envirostream) is undertaking an initial processing step	

How it works / principles

- This simple initial processing approach recovers Al and steel from the casings, Cu and plastic for local recycling
- Electrode coatings (Co, Ni) are exported as a mixed metal dust (black mass)



Passivation: Achieved in brine, by Ohmic discharge or ‘in process’ (during shredding), in process is most cost efficient and used for most large-scale recycling processes.

Disassembly: Owing to inconsistent battery types/poor labelling this is typically done manually, at a minimum this involves removal of metal or plastic covers.

Shredding: Shredding and milling is a minimum pre-processing step (and some technologies can directly passivate batteries), electrode coatings (metal oxides, carbon) end up in fines known as the ‘black mass’ or ‘mixed metal dust’, the foils and plastic end up in course fraction. The removal of polymeric binders from black mass may be required.

Physical separation: Materials can be recovered by a range of physical separation methods exploiting particle size, density, ferromagnetism, hydrophobicity.

Example: Envirostream, Victoria

- Envirostream is the only company undertaking a domestic pre-processing step, exporting cathodic powders (‘black mass’) for processing in Korea
- Al, Cu, steel and plastic is recovered for local recycling; the black mass containing Co, Ni, Li, Mn is exported under licence
- This economic model relies on the value of the Co, Ni; thus changes in LiB chemistry may impact viability

Reuse and Refurbishment Options

PV Panels

Whole PV panel reuse and refurbishment: A small number of international companies provide PV panel refurbishment operations. Cost-effectiveness and disincentives for use of secondhand PV panels remain the greatest barrier to increased uptake. Rinovasol claim to be able to refurbish 90% of decommissioned PV panels, through a patent protected technology.[16] They also recycle PV panels that cannot be refurbished using a low recovery pathway. PV Cycle, in partnership with Rinovasol estimated that ~ 480 MW of PV may be available for refurbishment (2014 – 2019) globally, however no regional breakdown or technical detail is available.[17] However, considering the NSW context, one stakeholder suggested that refurbishment could not cost more that $15/PV panel including transport in order to be economically viable based on the current price of new PV panels. In addition, warranties can have exclusions that decrease the capacity of systems to enter second-hand markets, such as warranties being voided if a PV panel changes location.[18]

Research indicates that a typical second-hand price for PV panels is around 70% of the original price.[19] However, stakeholder interviews and the literature identify that decommissioned working PV panels tend to be exported from Australia, particularly to Papua New Guinea, because they cannot receive small scale technology certificates in Australia, cannot be installed of roofs again, and do not come with the same quality assurance as a new PV panel.[20]

Reuse markets have been more successful in the European Union, potentially due to online platforms such as Second Sol, that provide module testing and repair, in addition to recycling and disposal options. In 2015, ~ 60 MW of new and used PV modules were traded.[21] Testing services offered by companies such as PV Lab Australia could potentially be utilised, but further research is required. [22]

Component reuse and refurbishment: Research indicates that technology is demonstrated to produce new PV panels from recovered components. One study estimates that recovering components from 100 used PV panels could produce about 42 new PV panels.[23] However, this is not practiced at any significant scale in Australia, potentially due to the low cost of new PV panels.

Batteries

Battery reuse, in principle, is likely to have better environmental outcomes than recycling, due to its lower material and energy requirements.

Stakeholders engaged currently in battery and e-waste recycling are committed to exploring LIB battery refurbishment due to perceived market opportunities. This interest is principally linked to forecast growth in the Electric Vehicle (EV) market, and consequent access to used batteries from this sector. The viability of battery reuse from PV applications must consequently be considered in relation to EV forecasts.

Technological capacity: In terms of technology, a number of refurbishment methods have passed the demonstration phase. Companies such as Relectrify in Melbourne claim to have “World-first control technology (that) unlocks full capacity of every series cell”.[24] Other research into LIB rejuvenation or remanufacture is currently underway, for example, technology intended to rejuvenate cathodes by bathing them in a soft chemical solution, may be more cost effective than recycling because it does not require the cathode to be rebuilt and keeps materials in form.[25] Another future pathway for rejuvenation involves the replacement of whole degraded cells in battery pack systems. In cases where degradation or failures occur as a result of a few cells failing, the direct swapping out for new cells could prolong the life of the battery pack overall.[26] However, for this to work would require that battery packs and systems be designed and constructed to enable cells to be swapped in this way.

Barriers: Despite the interest and commitment to battery reuse from industry, stakeholders indicate there are several issues inhibiting growth at present, including the need for a robust battery testing system that can quickly determine how many cells have failed. This process is currently prohibitively expensive. There were also issues raised associated with differences in battery sizing – due to specific product requirements – which creates challenges in terms of creating economies of scale. Further R&D into battery design may also help to resolve this issue. Another challenge noted by stakeholders is the lack of policy and protocols or certification around the reuse of batteries for energy storage.

Implications of Findings

The technology assessment conducted in this phase provides a detailed characterisation of the range of technologies for recovering materials from PV panels and batteries. The findings were used to define different recovery pathways for estimating material recovery in Phase 3 and technical and techno-economic feasibility assessments in Phases 4 & 5.

In the case of PV panels, technologies and recovery pathways have been categorsied as ‘low recovery’ and ‘high recovery’ pathways. ‘Low recovery’ pathways are defined as those that may not recover materials at a purity suitable for manufacturing new PV panels. The current activity in Australia may be characterised as ‘low recovery’. While low recovery is demonstrated overseas (e.g Europe) and can capture up to ~ 80 % (including glass, Al frames, junction box) further sorting and/or treatment may be required to manage a mixed residual stream of Si, other metals, plastic and glass fines from the low recovery pathway. A range of ‘high recovery’ pathways were reviewed that can recover intact silicon wafers and other metals require further development to achieve commercial deployment. These processes use high temperatures to decompose the polymeric binders and solvents for the recovery of metals that may result in hazardous emissions and liquid waste streams.[27]

LIB recycling involves a combination of mechanical and/or thermal pre-treatment steps, pyro- and/or hydrometallurgical processing that are mature processing technologies developed for e-waste processing as well as the recycling of discarded LIBs from other applications, e.g. Consumer electronics.[28] This review highlighted three pathways, ‘initial processing’, ‘recycling’ and ‘reuse’. The initial processing pathway was highlighted as this currently reflects the most advanced activity in Australia. This process can recover scrap and a mixed metal dust containing the valuable metals is exported for downstream processing.

Further Research Required

Establishing collection systems (decommissioning, transport and handling) that can support reuse and recycling of PV panels is a critical first step and further R&D is required to develop advanced processes for high value recovery for PV panels and managing / avoiding contaminated residual streams from low recovery pathways. Greater PV panel reuse and refurbishment could also be enabled through R&D into standardised testing and certification of secondhand PV panels through services such as those offered by PV Lab, and R&D into the potential for greater design for reuse. For batteries, while collection systems are emerging for discarded LIBs from other applications it is unclear how suitable these logistic solutions will be for larger storage batteries. Although battery recycling is relatively mature with commercial operations overseas (targeting discarded LIBs from other applications) further R&D support could encourage further processing onshore. In addition, battery re-manufacture or cell rejuvenation is a promising area that requires further R&D, particularly design innovation, to address complexities with disassembly to support rejuvenation.

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Phase 3 – Recovered Materials Assessments

Objectives

The objective of this phase was to estimate potential material recovery assuming likely recovery pathways for processing the projected waste volumes (estimated in Phase 1).

Approach

Drawing on a review of literature describing the status of recycling technologies, and stakeholder consultation (Phase 2) likely material recovery pathways were defined for PV panels and batteries. We assumed two material recovery pathways for both PV panels and batteries that reflect 'low recovery (PV panels) or initial processing (batteries)' and 'high recovery' pathways (PV panels and batteries). These are described in detail in the following pages. The primary literature that informed this assessment was:[1-3]

The defined recovery pathways were used to estimate the material recovery potential from the projected waste volumes estimated in Phase 1. The material recovery was estimated based on the shorter average lifetime for each technology (10 years for batteries, 15 years for PV). The analysis in Phase 3 provides estimates of the total material recovery from the recycling process, including losses in the process. It does not consider the rate of collection that is likely to be relatively low in the near term without government intervention (including the establishment of a product stewardship scheme), which is evaluated in Phases 4 and 5.

Assumptions

PV Panels

1) **Two recovery pathways were assumed for PV panels reflecting 'low recovery' and 'high recovery' pathways[4]**

- Low recovery involves manual removal of Al frames, junction box and Cu cables and shredding/crushing; the glass and Al is recovered by manual and mechanical separation representing ~77% (82 % incl junction box) of the discarded PV panel stream (Si, other metals, plastic and glass fines are not recovered ~ 18%)
- High recovery involves manual removal of Al frames, junction box and Cu cables followed by a delamination step (thermal) and further thermal/chemical processing to recover Si wafers and metals(Ag, Al, Cu) representing ~88 % (93 % incl junction box) of the stream

These pathways were selected based on our review of the technologies in Phase 2. The low recovery pathway reflects what is currently the most mature recovery pathway demonstrated in Europe and is likely representative of emerging activities in Australia that charge a gate-fee to receive PV panels and reclaim the Al frame (e.g. Reclaim PV). High recovery was defined to reflect the more advanced recycling approaches that aim to maintain the embedded value in the systems by targeting the recovery of in-tact Si wafers and the valuable metals. As discussed in Phase 2, these processes have been demonstrated at pilot scales and remain pre-commercial.[5]

Batteries

2) **Two recovery pathways were assumed for batteries aligned with 'initial processing' and 'recycling'[6,7]**

- Initial processing involves discharge, disassembly and shredding/crushing to produce a mixed metal dust ('black mass') consisting of Li, Co, Ni, other minor metals and graphite representing ~35 % of the discarded battery stream
- Recycling involves initial processing, thermal treatment and hydrometallurgical processing to recover battery-grade materials; A total material recovery rate of ~60 % is assumed that includes Li (lico$_3$), Co (hydroxide), Ni (hydroxide), Fe, Cu and Al (scrap); Material losses include the solvent, plastic and minor metals

These pathways were selected to align with current activities in Australia and likely recovery rates in industrialised recycling processes currently operating overseas. Specifically, the initial processing pathway was selected to reflect an assumed recovery rate achievable with the pre-processing steps undertaken by Envirostream[8]; and, the high recovery pathway represents current state of the art LIB recycling processes targeting the recovery of Co, Ni, LI, Fe, Cu and Al at purities suitable for cathode manufacturing.

We note that this analysis is focused on LIBs only. While LAB were previously the dominant technology. At that time the market was very small and hence waste volumes are small. Further, the recycling systems for used lead acid (ULAB) batteries is very mature and functions well, driven by the value of lead and large number of ULAB from vehicles. For this reason we only focuses on LIB for the recovered materials assessment in this phase and the subsequent technical (Phase 4) and economic feasibility (Phase 5) assessments.

PV Panels

Summary findings

1. For PV panels, significant volumes of crushed glass (~ 37,000 t by 2035) and Al (~ 11,500 t by 2035) are recovered by the low recovery pathway that represents a major fraction of the total waste volume (~ 80 %), however valuable Si and other metals are not recovered without further processing.
2. The high recovery pathway (that involves a delamination and further processing) can recovery > 90 % of the total waste volume including high purity Si and Ag.[9,10]

As noted in Phase 2, while the low recovery pathway operates at industrialised scales overseas and can potentially recover ~80 % of the material (frames, glass, junction box) this assumes that the crushed glass meets market specifications and further clarification from glass reprocessors is required. Given PV recycling is very immature in Australia this remains uncertain without further research.[11] Considering the unrecovered material (~20% or 11,500 tonnes by 2035 according to the low recovery pathway), this could present a significant process risk by producing a contaminated residual stream (glass fines, polymeric binders, metals) that requires further treatment or disposal. While a range of treatment processes are being investigated (see Phase 2), further R&D is required. Chemical processes investigated for delamination and metal recovery use solvents and would likely produce a liquid waste stream.

This analysis assumes the short lifespan (15 years) modelled in Phase 1 that has a significant impact on the estimated waste volumes and the totals reported do not consider a collection rate that would likely be very low in the near team without policy intervention. This will be discussed in Phase 5.

Key takeaway message: Low recovery pathways are demonstrated overseas and being explored by recyclers in Australia however future potential of this pathway relies on demonstrating that there is a market for the recovered glass. These processes also likely produce a residual stream requiring further treatment and disposal. Further R&D is required to develop advanced processes that overcome these challenges by promoting reuse and/or the recovery of valuable Si and metals for manufacturing new PV panels.

Batteries

1) For LIB, initial processing can recover steel, Cu, Al and a mixed metal dust (Co, Li, Ni), however further processing is required to recover valuable metals; the annual recovery of mixed metal dust (black mass) could reach ~ 2000 tonnes by 2035 noting that this represents about 35% of the total waste stream
2) The black mass requires further processing in the LIB recycling process to reclaim Li , Co, Ni and graphite; the annual recovery could reach ~1400 tonnes by 2035

Phase 3 estimated the material recovery potential assuming an initial processing pathway. According to the projected waste volumes, and assuming all discarded LIB are available for recovery, ~ 2000 tonnes of black mass and ~ 2000 tonnes of scrap (Al, Cu, Fe) could be reclaimed per year by 2035. This represents 70 % of the stream however further processing of the black mass is required to recover materials for battery manufacturing. Downstream processing can recover ~ 1400 tonnes of valuable metals and graphite from the black mass such that the overall material recovery rate is about 70 % as there a further losses (e.g. Associated with thermal processing).[12,13]

Key takeaway message: The domestic initial processing route for LIB currently operating in Australia can divert about 70 % of the waste stream from landfill, however further processing of the black mass is required to recover valuable Li, Co, Ni and graphite for battery manufacturing. Presently, this domestic recycling activity is mostly targeting discarded small batteries (e.g. From mobile phones, power tools) and the downstream processing capacity does not exist in Australia. The projected volumes of black mass from LIB from energy storage applications alone is unlikely justify investment in the further processing steps onshore, however total waste volumes including from consumer electronics and evs could be significant.

Key Stakeholder Insights

Factor	Description
1: PV PANEL RECOVERY PATHWAYS	• The main recovery pathway currently available (internationally) for PV panels uses mature technology developed for e-waste; Al frames, junction boxes, Cu cables and most of the glass is recovered • While technology (delamination/thermal/chemical processing) to recover Si-wafers is not yet available in commercial plants, scalable solutions could be developed in <5 years; • One company in SA is developing technology based on a pyrolysis approach; • Collection logistics (incl. Handling that avoids breakages, high transport costs) is a barrier for recycling and reuse; Mobile shredders could address logistics challenges.
2: BATTERY RECOVERY PATHWAYS	• A combination of mechanical, thermal and chemical processes are available (internationally) for recovering battery-grade materials; • One company in Victoria (VIC) does initial processing onshore and exports a mixed metal dust for further processing (thermal/ hydro met); • Most recyclers are not looking to develop hydro met facilities onshore at this time; • The key challenge is scaling up a network of collection channels (for all EOL LIB); • EOL LIB are classified as a dangerous good and transport legislation and the lack of a nationally consistent approach is a barrier; Changing chemistries may present a challenge in terms of revenues however the processing technology (hydro met) is capable of handling.

PV Recycling Material Recovery

Figures 14 & 15 compare the cumulative estimated volume of recovered materials by 2035 (tonnes) for low and high recycling processes (assuming a 15 year lifespan).

These figures show that high recovery PV recycling can recover 93% of materials compared to 82% in a low recovery process.

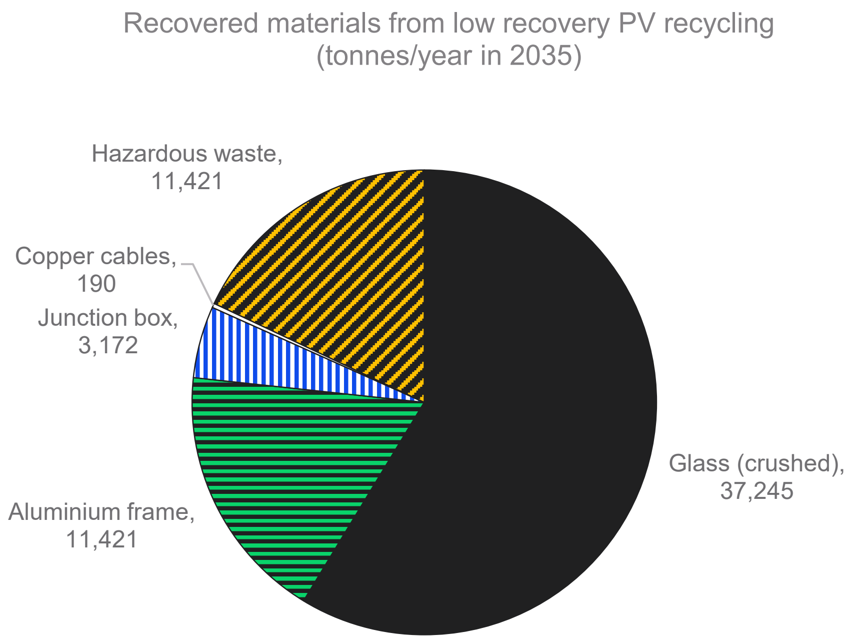

Figure 14: Recovered materials form low recovery PV recycling

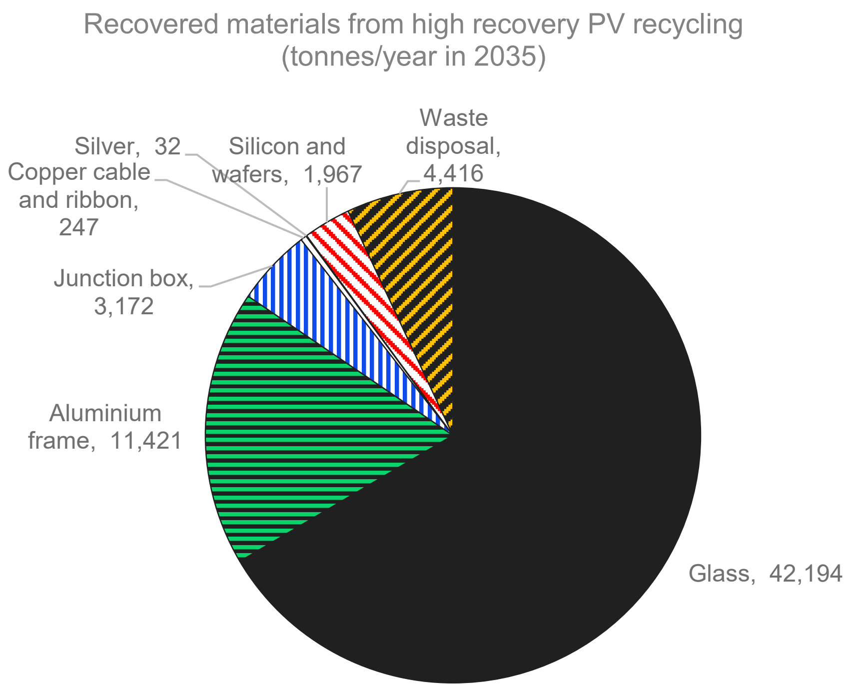

Figure 15: Recovered materials from high recovery PV recycling

Figures 16 & 17 compare the year-on-year estimated volume of recovered materials (tonnes) between initial processing and recycling (assuming a 10 year lifespan).

Significant volumes of crushed glass and Al are recovered by the low recovery pathway, however, valuable silicon and other metals are not recovered.

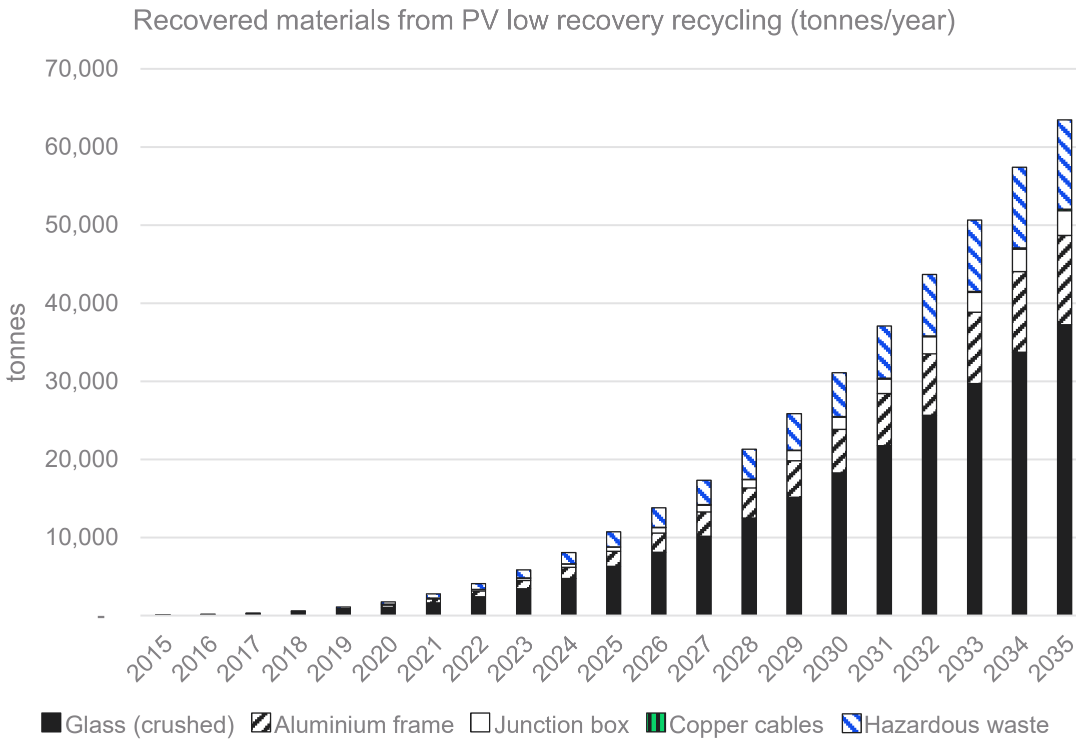

Figure 16: Recovered materials from low recovery PV recycling

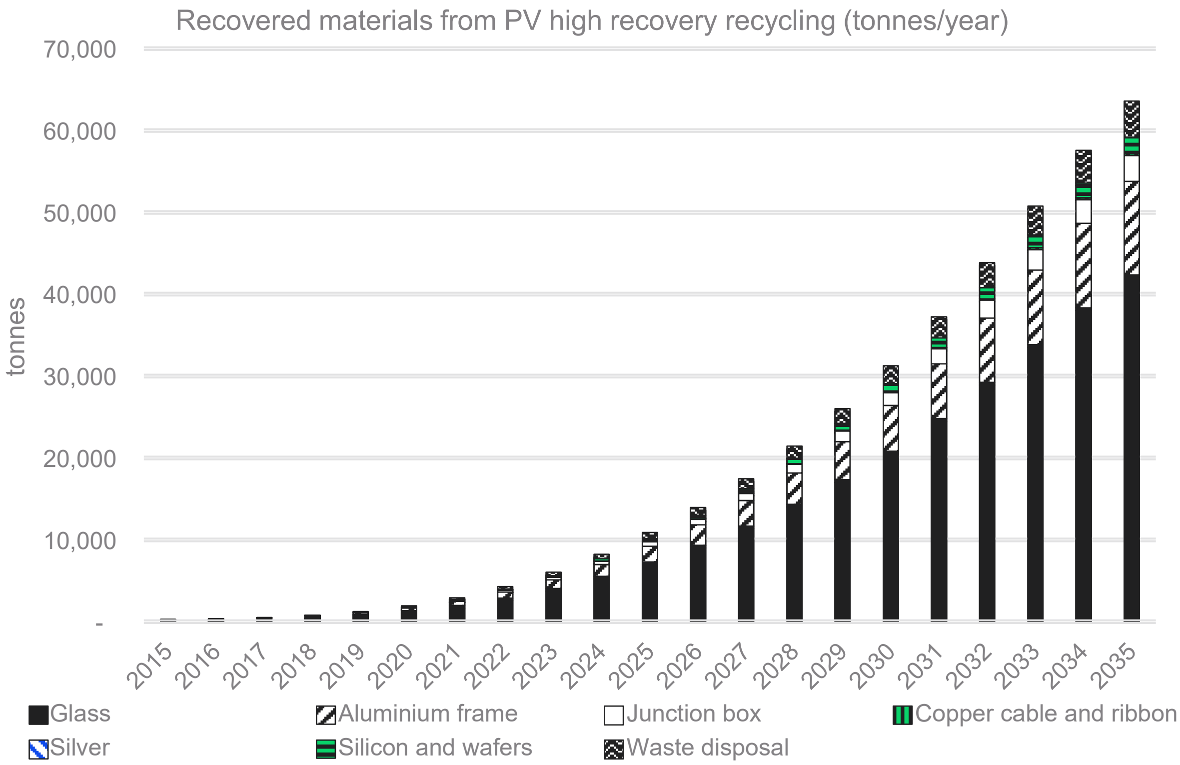

Figure 17: Recovered materials from high recovery PV recycling

Battery Recycling Material Recovery

Figures 18 & 19 compare the cumulative estimated volume of recovered materials by 2035 (tonnes) between initial processing and recycling (assuming a 10 year lifespan). They demonstrate that initial processing recovers steel, Cu, Al and a mixed metal dust (Co, Li, Ni), further processing is required to recover valuable metals.

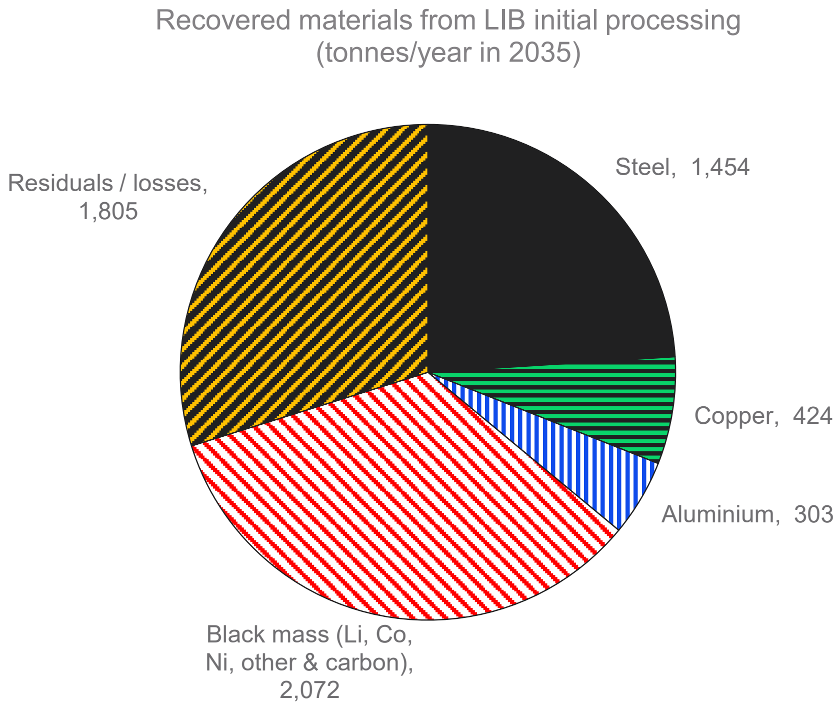

Figure 18: Recovered materials from LIB initial processing

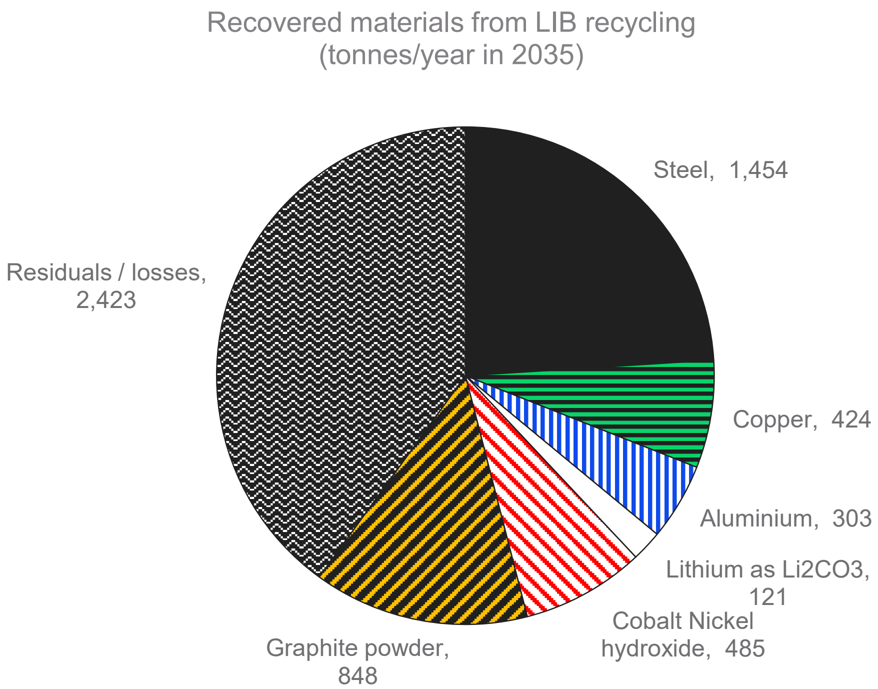

Figure 19: Recovered materials LIB recycling

The Figures 20 & 21 compare the year-on-year estimated volume of recovered materials (tonnes) between initial processing and recycling (assuming a 10 year lifespan).

The annual recovery of mixed metal dust could reach ~ 2000 tonnes by 2035, or with further processing ~ 1400 tonnes of Co, Li, Ni and graphite.

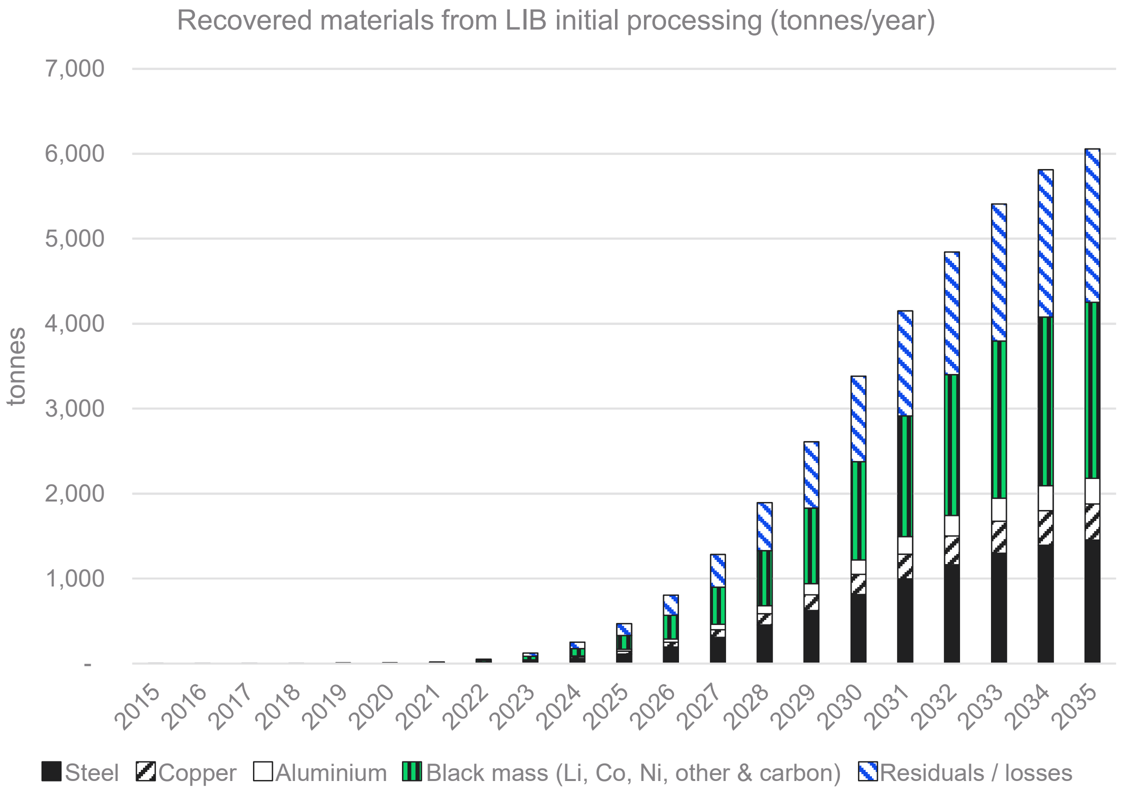

Figure 20: Recovered materials from LIB initial processing

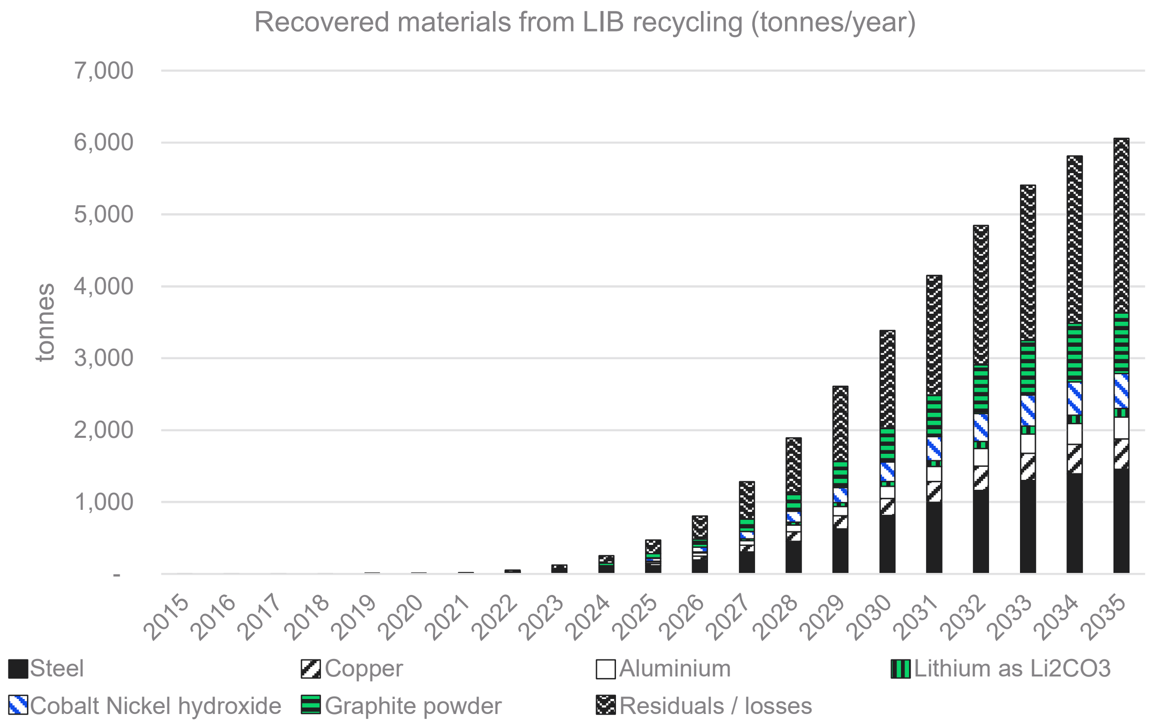

Figure 21: Recovered materials from LIB recycling

Implications Of Findings

The modelling undertaken in this Phase highlights a range of material recovery opportunities depending on the assumed material recovery pathways. The estimated material recovery (by material, by year) was used as the input for the technical feasibility assessment in Phase 4 and the economic feasibility assessment in Phase 5.

For PV panels, the low recovery pathway that is demonstrated overseas, and being developed by recyclers in Australia, can recover significant volumes. However, this finding assumes that the crushed glass meets market specifications and there remains some uncertainty about the quality of the recovered glass and market potential, (see footnote 14). This pathway has a number of associated risks including: 1) the creation of residual materials, some of which may be hazardous, that cannot be adequately recovered; 2) stockpiling of glass; and 3) investment in infrastructure for this pathway may lock companies into this form of processing and be a disincentive for investment in higher recovery pathways in future.

In the case of LIB we estimated the projected volumes of black mass from the initial processing approach aligned with one operation in Victoria. This analysis highlighted that although this initial processing route can divert significant volumes from landfill, the projected volumes of black mass from LIB from energy storage applications is relatively small. Furthermore, comparing the initial processing with the high recovery pathway highlights the lost value when Co, Ni, Li is exported overseas.[15]

Further Research Required

For PV panels, the uncertainty around the quality of the recovered glass reclaimed by the low recovery pathway is a clear area for further research and investigation. This should focus on better characterisation of the quality of the crushed glass as well as the residual stream (glass fines mixed with polymeric binder and metals) that are shown to arise in not insignificant volumes. The uncertainty around the quality and market availability may lead to stockpiling and undermines the economic viability of this pathway (discussed further in Phase 5).

Phase 3 References

1. Bartosinski, M. (2017). Processing of spent Li-ion batteries: Environmental Challenges, ICBR, Lisbon 2017
2. Deng, R., Chang, N. L., Ouyang, Z., & Chong, C. M. (2019). A techno-economic review of silicon photovoltaic module recycling. *Renewable and Sustainable Energy Reviews*, *109*, 532-550
3. Friedrich, B., & Peters, L. (2017) Status and trends of industrialised Li-ion battery recycling processes with qualitative comparison of economic and environmental impacts, ICBR, Lisbon 2017
4. Deng, R., Chang, N. L., Ouyang, Z., & Chong, C. M. (2019). A techno-economic review of silicon photovoltaic module recycling. *Renewable and Sustainable Energy Reviews*, *109*, 532-550
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6. Bartosinski, M. (2017). Processing of spent Li-ion batteries: Environmental Challenges, ICBR, Lisbon 2017
7. Friedrich, B., & Peters, L. (2017) Status and trends of industrialised Li-ion battery recycling processes with qualitative comparison of economic and environmental impacts, ICBR, Lisbon 2017
8. King, S., Boxall, N. J., & Bhatt, A. (2018). Lithium battery recycling in Australia
9. Deng, R., Chang, N. L., Ouyang, Z., & Chong, C. M. (2019). A techno-economic review of silicon photovoltaic module recycling. *Renewable and Sustainable Energy Reviews*, *109*, 532-550
10. Cutting, J., & Gietman, A. (2019). PV panel reprocessing: Research into silicon-based photovoltaic cell solar panel processing methods, viable materials recovery and potential end market applications. Report for Sustainability Victoria, October 2019
11. Ibid
12. Friedrich, B., & Peters, L. (2017) Status and trends of industrialised Li-ion battery recycling processes with qualitative comparison of economic and environmental impacts, ICBR, Lisbon 2017
13. King, S., Boxall, N. J., & Bhatt, A. (2018). Lithium battery recycling in Australia
14. Cutting, J., & Gietman, A. (2019). PV panel reprocessing: Research into silicon-based photovoltaic cell solar panel processing methods, viable materials recovery and potential end market applications. Report for Sustainability Victoria, October 2019
15. King, S., Boxall, N. J., & Bhatt, A. (2018). Lithium battery recycling in Australi

Phase 4 – Technical Feasibility Assessment

Objectives

The technical feasibility assessment of PV panels and batteries considers the most promising collection, reuse and recycling methods that have been previously identified in this study and assesses which are feasible or not in the NSW context.

Approach

Drawing on the review of existing technologies identified in Phase 2 and the findings of Phase 3, this stage of the study included stakeholder interviews to gather contemporary knowledge and data on current collection, reuse and recycling practices. It also included a review of reports and publications about current and emerging collection, reuse and recycling approaches, technologies and systems.

Primary source data was gathered from most current processors that are operating in NSW or elsewhere in Australia, companies that are either currently processing PV and / or batteries or are in advanced planning to establish processing facilities, whether in NSW or elsewhere in Australia. Different scenarios were developed to enable assessment of current practices for both PV and batteries. Specifically, four scenarios were developed reflecting the low and high material recovery pathways defined in Phase 3 and considering participation rates with or without a product stewardship scheme. The data from Phases 2 and 3 was used to inform the assumptions in each scenario, and for the scenarios with a product stewardship it is assumed that fundamentally product stewardship will incentivise a higher participation rate, and therefore more materials will be available for collection and processing sooner.

A risk ranking framework was developed that enabled a technical feasibility assessment for each scenario in the NSW context. The assessment looked at ten factors outlined in the following table. The factors were assessed based on the industry data and knowledge gathered in stakeholder consultations and the earlier phases.

Risk Ranking Factors

As noted earlier, the technical feasibility assessment employed a risk ranking approach to inform whether it is currently feasible or not to collect and recycle PV panels and batteries in NSW. Based on stakeholder interviews, existing research and general market intelligence, a series of factors were identified as being important to the success or otherwise of facilities in NSW. The following sets out those factors and why they are considered important.

Factor assessed	Reason / Importance
Source of material	Where is the waste material being generated and what is the collection capacity?
Material composition	What is the potential to cause environmental or human harm?
Current / future volumes	What amounts of material are available for recovery?
Current technology	Is resource recovery technology available and proven?
Need for new facilities	Is there a need for more capability and capacity to recover materials?
Resource recovery	What is current capability and capacity to recover materials?
Export amounts	Is material exported and what is the potential for future local markets?
Overseas markets	Is there downstream accountability, maturity and sound disposal?
Regulations	What is the potential for regulations to impact resource recovery?
Industry standards	What is the potential for standards to impact resource recovery?

Summary Findings

PV Panels and Batteries

- Recycling technology and systems are still in development and without some form of market intervention it is not currently likely that either PV or batteries will have economically sustainable collection, reuse and recycling systems in NSW in the near future.
- PV and batteries follow different pathways for collection, reuse and recycling owing to different product lifecycles, different material compositions. As such, the facilities to process batteries and PV are different. Batteries will be able to be processed for either low or high material recovery in facilities that are processing a range of batteries from a range of sources. PV however will need specialised and dedicated equipment and facilities. Correspondingly, the recovery and processing technologies, plant and equipment and business models are different.
- E-waste processors are actively investigating opportunities to process PV panels.
- Current e-waste processing technology and systems only target the Al frames, and specialised and dedicated plant and equipment is needed to more fully process PV panels.
- Stakeholders are planning for PV reuse facilities and businesses however insufficient technical detail is available at present to determine whether reuse is sustainable not.
- Presently, low material recovery approaches are likely to lead to stockpiling of PV after the frame is removed.
- For batteries the recovery and subsequent reuse or recycling pathways are relatively advanced and more likely to scale-up quickly.
- The export of PV panels or batteries in whole or part for processing, either interstate or overseas, is likely.

Key takeaway messages:

- Industry is looking for market interventions in order to establish facilities and Stakeholders express confidence in the future feasibility of PV and battery collection, recycling and reuse but are still in the research / planning / commissioning phase of business development.
- Many stakeholders report that the most fundamental issue for both PV and batteries is the need to access and secure sufficient volumes of materials in order to justify investment in plant and equipment and technology.
- With respect to market interventions, many stakeholders reported that they expect product stewardship to support the sustainability of collection and processing activities, and that it would will bring forward greater participation rates especially for PV.

Key Stakeholder Insights

Factor	Description
1: PV PANEL PROCESSING AND RECOVERY	• Technology and systems still are developing, and yet not available locally • There is uncertainty about availability of, and access to, materials • Technology from Japan and Europe are broadly favoured • There is interest in national product stewardship • Interest and enthusiasm expressed were not commensurate with current capabilities
2: PV PANEL REUSE	• Industry expectations are that reuse can be viable, however it is unclear how or when that may be • Collection, handling and storage present significant barriers, and solutions are not yet apparent • Refurbishment and reuse could be better supported by manufacturer and supplier warranties
3: BATTERIES & ENERGY STORAGE	• It is desirable that solar-connected batteries and energy storage systems are part of wider recovery, reuse and recycling networks under development by battery recycling businesses • Technology and systems are advanced and still maturing • There is potential to scale up operations further • Battery chemistry will significantly influence business models
4: RECOVERY RATES	• Existing technology and infrastructure for battery recovery rates are in excess of about 70% • Existing technology and recovery rates for PV panels are about 20% • Increasing recovery rates locally will require significant investment • Installers will also be key to PV panel recovery

PV Panel Scenarios

Four scenarios were developed to enable assessment of current PV recovery pathways based on low or high material recovery rates, and consistent with Phases 2 and 3, and with or without product stewardship. The findings from Phases 2 and 3 were used to inform the material recovery rates. Based on how product stewardship schemes generally are structured and operate, it is assumed that a product stewardship scheme for PV panels will encourage greater participation, thereby leading to higher recovery rates.

Scenario	Description	Assumptions and observations
Low material recovery	Mechanical processing and shredding	• ~ 80 % material recovery rate (Al frame, crushed glass, Cu cables) • All processed locally (NSW and Australia)
High material recovery	Thermal and chemical treatment	• 90 % material recovery rate • Rare and precious metals recovery • Processing locally and overseas
Low material recovery with product stewardship	Mechanical processing and shredding	• As above but with subsidised collection and processing • Higher participation rates
High material recovery with product stewardship	Thermal and chemical treatment	• As above but with subsidised collection and processing • Higher participation rates

Battery Scenarios

Four scenarios were developed to enable assessment of the current technical feasibility of battery recycling based on low or high material recovery rates aligned with the outcomes from Phases 2 and 3 and with or without product stewardship. The findings from Phases 2 and 3 were used to inform the material recovery rates. As noted above, It is assumed that a product stewardship scheme for batteries will encourage greater participation, thereby leading to higher participation and recovery rates.

Scenario	Description	Assumptions and observations
Initial processing	Basic separation and mechanical processing	• 70% material diversion (~35% mixed metal dust containing Li, Co, Mn, Ni requiring further processing) • All processed locally (NSW and Australia)
Recycling	Initial separation and then hydrometallurgical processing route with mechanical and thermal processing	• ~ 60 % material recovery rate • Rare and precious metals recovery • Processing locally and overseas
Initial processing with product stewardship	Basic separation and mechanical processing	• As per 1 but with subsidised collection and processing • Higher participation rates
Recycling with product stewardship	Initial separation and then hydrometallurgical processing route with mechanical and thermal processing	• As per 2 but with subsidised collection and processing • Higher participation rates

Assessment framework for technical feasibility

An assessment framework was developed to review the technical viability of the different scenarios. From earlier research and stakeholder input, key factors that influence feasibility were identified and these are detailed earlier on page 48 "Risk Ranking Factors".

These factors were individually assessed for PV and batteries against the four scenarios for each PV and batteries.

The factors were ranked with a standard risk assessment approach to determine whether the factor presents a risk to the technical feasibility of the collection and processing of PV and batteries in NSW now or in the near future.

In short, the higher the risk ranking, the less technically feasible the collection and processing is as a sustainable activity without any intervention.

A traffic light assessment process was sued to illustrate the risk ranking and whether collection and processing is technically feasible.

The traffic light employs the following colour coding.

Green	Green indicates that the factor identified is manageable or low risk with current technologies and systems
Yellow	Yellow indicates that technology or systems are conditionally feasible or medium risk when addressing the factor and that further development is needed
Red	Red indicates that the technology or systems are not currently feasible and are high risk when addressing the factor

Overall, with respect to the following two pages, the greener a scenario is, the more technically feasible it is at present. Further details are provided in the Appendix.

PV panels

At present it is not technically feasible to collect and process PV panels in NSW within any scenario. Lack of material volumes, access to processing technology and the need to establish new facilities are notable current risks to technical feasibility.

SOURCE	Source of material occurrence of waste material	Material com-position	Current and future volumes	Current tech' availability	Need to create new facilities	Resource recovery / landfill diversion	Overseas exports - amount exported	End use exports - tracking system maturity	Regulation by juristiction	Industry standard
Low material recovery	Red	Yellow	Green	Red	Yellow	Red	Green	Green	Green	Green
High material recovery	Red	Yellow	Green	Red	Yellow	Red	Green	Green	Green	Green
Low material recovery (with PS)	Yellow	Yellow	Green	Green	Yellow	Green	Green	Green	Green	Green
High material recovery (with PS)	Yellow	Yellow	Green	Green	Yellow	Green	Green	Green	Green	Green

* Product Stewardship (PS)

Batteries

A number of issues must still be addressed for battery collection and processing to become technically feasible. However, for batteries, the issues may be resolved more easily as processing facilities will be receiving and processing a range of different batteries from different sources, and do not rely on PV systems exclusively.

SOURCE	Source of material occurrence of waste material	Material com-position	Current and future volumes	Current tech' availability	Need to create new facilities	Resource recovery / landfill diversion	Overseas exports - amount exported	End use exports - tracking system maturity	Regulation by juristiction	Industry standard
Initial processing	Green	Yellow	Green	Green	Yellow	Green	Yellow	Green	Green	Green
Recycling	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green	Green
Initial processing (with PS)	Green	Yellow	Green	Green			Yellow	Green	Green	Green
Recycling (with PS)	Green	Yellow	Green	Green	Yellow	Yellow	Yellow	Green	Green	Green

* Product Stewardship (PS)

Implications of Findings

PV panels and batteries follow different paths for collection, reuse and recycling due to their different lifecycles and different material composition. This differentiation influences the technical feasibility of different pathways, as the options utilised to recover the two types of products must be independently viable, even if they have complimentary elements. Overall, recycling technology and systems are still in development and will require some form of market intervention to ensure that both PV and batteries will have sustainable collection, reuse and recycling systems in NSW in the near future.

Battery recycling is likely to be feasible sooner than PV panels in NSW. This is because batteries can be processed in facilities that are recycling a range of batteries from different sources and because recovery and subsequent reuse or recycling for batteries is reasonably advanced and likely to scale-up quickly.

For PV panels, the current processing is characterised by frame removal and stockpiling and current material recovery is focused on the Al frame. For the recovery of more materials from PV panels, new, dedicated facilities are required.

Further Research Required

PV processing, whether a low or high material recovery, needs to ensure the glass is able to be diverted from landfill and into other processes because it is such a high component of the PV by weight and area. However, published reports and stakeholder claims are somewhat divergent when it comes to glass recovery. Low material recovery processes that cannot liberate glass from the Si wafers seems inconsistent with being able to recover the glass for further use. High recovery pathways employing thermal technologies reportedly alter the glass and may limit opportunities for further processing. Overall, the pathways and fate of PV glass warrants more research.

There is a lack of detail about the reuse pathway for PV. Further demonstration and pilot activities should be developed to test collection and aggregation of PV panels for recycling and reuse, and to evaluate processes and economics for differing battery chemistries.

Phase 5 – Economic Viability Assessment

Objectives

This section uses existing research and the findings from earlier phases of this project in order to examine the uses and end markets of materials recovered from PV and battery recycling, to identify the economic viability of such activities and what further research or actions may be needed to establish those uses and end markets in NSW.

Approach

To investigate the economic viability of recycling PV panels and batteries, a review was undertaken of current data on the existing financials associated with all elements of PV panel and battery collection, handling and processing. This includes the following with the data source in brackets.

Elements of collection	Data
Cost of collection	Industry interviews and existing reports
Cost of infrastructure	Industry interviews and existing reports
Operational costs cost of resource recovery processes	Industry interviews
Volume of recovered materials	Phase 3 of this study
End uses and market value for recovered materials	Industry interviews and commodity market intelligence reports
Other current and projected market conditions	Industry interviews
Weight to unit estimate	Phase 1 of this study

Four scenarios were assessed (consistent with those defined in Phase 4) for both PV panels and batteries. This included low and high material recovery scenarios, with and without product stewardship. The details describing the scenarios and key assumptions are provided on the following pages.

The first part of the economic viability assessment was to determine the margin per tonne (pre-tax / gross financial margin) that could be achieved in the four scenarios. This included estimating the following inputs:

- Gate fee (a charge per tonne to collect and receive PV panels or batteries)
- Commodity recovery values (the sale price per tonne of the commodities / materials recovered from recycling)
- Processing costs (the cost per tonne to run the recovery facility and extract the commodities / materials for sale)

The second part of the assessment was to investigate how much volume of material may be needed per year for a PV recycling facility to achieve a return on investment (ROI) of 2.5 years for capital expenditure. These calculations were based on the margin calculated in the first part of the assessment and estimates of capital expenditure.

The economic modelling and the assessment illustrates the economic conditions likely needed for the collection and recycling of PV panels and batteries to be economically viable in NSW. While the modelling and assessment for PV panels and batteries was conducted in the same manner, the assessments are not directly comparable as the pathway and processes for PV panels and batteries are different involving separate and distinct activities. The economic viability assessment evaluates recycling of PV panels and batteries, insufficient data is available at this time to undertake a detailed economic assessment on the reuse of PV panels or batteries.

Summary Findings

PV Panels

- The value of the commodities that can be recovered from PV PV panels does not cover the processing costs, necessitating a gate fee
- Low material recovery operations recover glass, Al, Cu and some plastics – estimated to be about 80% of the total weight / volume of a PV panel; High material recovery operations recover glass, Al, Cu, rare metals and silicon and wafers – estimated to be more than 90% of the total weight / volume of a PV panel
- It is assumed that high material recovery operations recover better quality glass
- Low material recovery facilities capital cost is estimated to be about AUD$1.5m for about 1500 tonne per annum capacity
- Low material recovery facilities operational cost is estimated to be about $650 per tonne and at a $14-$15 per unit gate fee is estimated to achieve a gross margin of $5.70 per unit or $270 per tonne
- High material recovery facilities capital cost is estimated to be about AUD$7m for about 4500 tonnes per annum capacity
- High material recovery operational cost is estimated to be about $1120 per tonne and at a $14-$15 per unit gate fee is estimated to achieve a gross margin of $10 per unit or $470 per tonne
- To cover capital costs and provide a return on investment within 2.5 years, a low material recovery facility will need about 1500 tonnes of PV panels per annum, and a high material recovery facility will need about 4500 tonnes per annum
- We note that economic viability is sensitive to assumptions around the fate of the glass, specifically whether some or all of the glass is recoverable, or whether some has to be disposed to landfill

Batteries

- Used LIB will be able to be processed by recyclers and in facilities that are processing a range of different batteries from a range of different sources
- The value of the commodities that can be recovered from batteries does not cover the processing costs and a gate fee is needed
- The initial processing/ low material recovery pathway for batteries recover steel, Cu and Al and a black mass for downstream processing
- The high material recovery also recovers lithium carbonate, cobalt nickel hydroxide and graphite powder
- Low material recovery facilities operational cost is estimated to be about $1560 per tonne and at a gate fee of about $160 average per unit gate fee is estimated to achieve a gross margin of about $70 per unit or $675 per tonne
- High material recovery operational cost is estimated to be about $1730 per tonne and at a gate fee of about $160 per unit gate fee is estimated to achieve a gross margin of about $80 per unit or $740 per tonne
- It is not practical to assess the ROI time frame for batteries as batteries will be processed with a range of other batteries from a range of other sources, and therefore ROI will be determined by a range of factors not assessed for this study

PV Scenarios

Four scenarios were developed to assess PV based on low or high material recovery rates (defined in Phase 2 and 3) with or without product stewardship. Findings from Phase 3 informed the material recovery rates and industry insights inform the initial participation rate and rate of growth. Based on industry feedback, all scenarios assumed that glass will be recovered and not landfilled. Further investigations may be necessary to better understand potential glass recovery and recycling approaches that remain untested in the NSW context.

PV panels	
Scenario	**Assumptions**
P1. Low material recovery	• 82% material recovery rate (Al, crushed glass and Cu recovered) • 5% initial participation rate • Low growth in participation rate (1% per year)
P2. High material recovery	• 93% material recovery rate (Al, crushed glass, Cu, rare metals and precious metals recovered) • 5% initial participation rate • Low growth in participation rate (1% per year)
P3. Low material recovery with product stewardship	• As per P1 • 5% initial participation rate • Medium growth in participation rate (2% per year)
P4. High material recovery with product stewardship	• As per P2 • 5% initial participation rate • Medium growth in participation rate (2% per year)

PV Participation rate and volumes

An assessment was completed for PV panels looking at the volume of discarded PV panels arising each year with and without a product stewardship scheme. A participation rate was therefore determined in order to be able to calculate the possible volumes available to be recycled. Based on stakeholder feedback and general market intelligence, it was assumed that without a product stewardship scheme the participation rate would be low and remain low. The participation rate increases more rapidly with a product stewardship scheme.

The tables below show the assumed volumes of PV panels being available for recycling in NSW, without and with, product stewardship.

PV panels – estimated participation rate and tonnes *without* product stewardship											
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Participation rate	5%	6%	7%	8%	9%	10%	10%	10%	10%	10%	10%
Tonnes per year	88.54	165.6	287.6	469.6	726.6	1,072	1,379.9	1,730.9	2,129.3	2,584.9	3,109.1

PV panels – estimated participation rate and tonnes with product stewardship											
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Participation rate	5%	7%	9%	11%	13%	15%	17%	19%	21%	23%	25%
Tonnes per year	88.5	193.2	369.8	645.7	1,049.5	1,608.1	2,345.8	3,288.6	4,471.5	5,945.2	7,772.6

Battery Scenarios

The four scenarios developed to assess batteries are based on low or high material recovery rates with or without product stewardship.

Findings from Phases 2 and 3 helped inform the assumptions about material recovery rates and industry insights informed the starting participation rate and rate of growth.

Batteries	
Scenario	Assumptions
B1. Low material recovery	• 36% material recovery rate (Al, crushed glass and Cu recovered) • 5% initial participation rate • Medium growth in participation rate (2% per year)
B2. High material recovery	• 60% material recovery rate (Al, crushed glass, Cu, rare metals and precious metals recovered) • 5% initial participation rate • Medium growth in participation rate (2% per year)
B3. Low material recovery with product stewardship	• As per B1 • 5% initial participation rate • High growth in participation rate (3% per year)
B4. High material recovery with product stewardship	• As per B3 • 5% initial participation rate • High growth in participation rate (3% per year)

Batteries participation rate and volumes

An assessment was completed for batteries looking at the volume of waste arising each year with and without a product stewardship scheme. Based on stakeholder feedback and general market intelligence it was assumed that without a product stewardship scheme the participation rate would be low and remain low, but that with product stewardship participation would increase more rapidly.

As the following tables indicate, the volumes of batteries being available for recycling in NSW will be low in the short term unless some significant event or intervention greatly increases participation. However, it is also noted that batteries more generally is a large and growing waste and recycling opportunity, and therefore solar connected batteries will be included in recovery and recycling pathways along with a range of other batteries from a range of sources.

Batteries – estimated participation rate and tonnes *without* product stewardship											
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Participation rate	5%	7%	9%	11%	13%	15%	17%	19%	21%	23%	25%
Tonnes/ year	0.3	1.3	4.6	13.5	32.9	70.5	137.2	243.8	397.6	600.2	845.7

Batteries – estimated participation rate and tonnes *with* product stewardship											
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Participation rate	5%	8%	11%	14%	17%	20%	23%	26%	29%	32%	35%
Tonnes/ year	0.33	1.43	5.68	17.22	43.00	94.02	185.62	333.59	549.01	835.01	1,184.02

Recovered commodities value

The economic assessment calculated how much of each different material or commodity can be recovered under the different scenarios. The end-market and market value for the different commodities was researched and documented to determine the revenue that could be generated from recovery and recycling in NSW. This review found:

- Strong and available end markets exist for most of the materials that can be recovered from PV panels and batteries in NSW
- Industry stakeholders and existing reports claim that glass recovered from PV panels is able to be recycled and strong markets exist, however, from research for this report it is unclear whether the glass recovered from PV panels can meet specifications for remanufacturing. It is also noted that the overall market for recovered glass from a range of sources is under pressure and undergoing significant change

Recovered commodities[1-3]					
Element	**Value (per tonne)**	**Data source**	**Element**	**Value (per tonne)**	**Data source**
Glass	$ -	16	Steel	$ 120.00	16
Al	$1,000.00	16	Cu	$ 5,000.00	17
Junction box	$46.40	16	Li2Co3	$ 1,787.10	18
Ag	$533,000.00	17	Coh$_4$nio$_4$	$ 1,709.53	19
Si and wafers	$12,963.00	17	Graphite Powder	$ 2,991.67	17

Economic Viablity Assessment

As outlined in the approach, the economic assessment has calculated the revenue inputs (gate fee and recovered commodity value or sale) and the operating or processing costs to determine how much margin per tonne may be achieved under the different scenarios. This approach found that the revenue earned from selling the commodities is not sufficient to cover the processing costs and that a gate fee is needed for both PV and batteries to be economically viable. The inputs and results of the material assessment, measured in tonnes and units (250w PV panels or average energy storage battery), are presented below.

Per tonne estimates for low and high recovery of PV and batteries				
Material Recovery	**Gate Fee ($/tonne)**	**Recovered commodity ($/tonne)**	**Processing ($/tonne)**	**Margin ($/tonne)**
PV - Low Recovery	$722.50	$197.32	$650.00	$269.82
PV - High Recovery	$722.50	$870.17	$1,120.00	$472.67
Battery - Low Recovery	$1,447.50	$785.85	$1,560.00	$673.35
Battery - High Recovery	$ 1,447.50	$ 1,020.14	$1,730.00	$737.64

Per unit estimates for low and high recovery of PV and batteries				
Material Recovery	**Gate Fee ($/Unit)**	**Recovered commodity ($/unit)**	**Processing ($/unit)**	**Margin ($/unit)**
PV - Low Recovery	$15.35	$4.19	$13.81	$5.73
PV - High Recovery	$15.35	$18.49	$23.80	$10.04
Battery - Low Recovery	$156.48	$84.95	$168.64	$72.79
Battery - High Recovery	$156.48	$110.28	$187.02	$79.74

PV panel collection and processing total revenue in NSW

An assessment of the volumes of the EOL PV panels arising and the revenue that can be generated from gate fees and the sale of recovered commodities indicates the total revenue that PV panels as an activity may generate over time. As Figure 22 shows, while starting very slowly due to the relatively small volumes of waste PV panels arising, over time the activity will generate significant revenue.

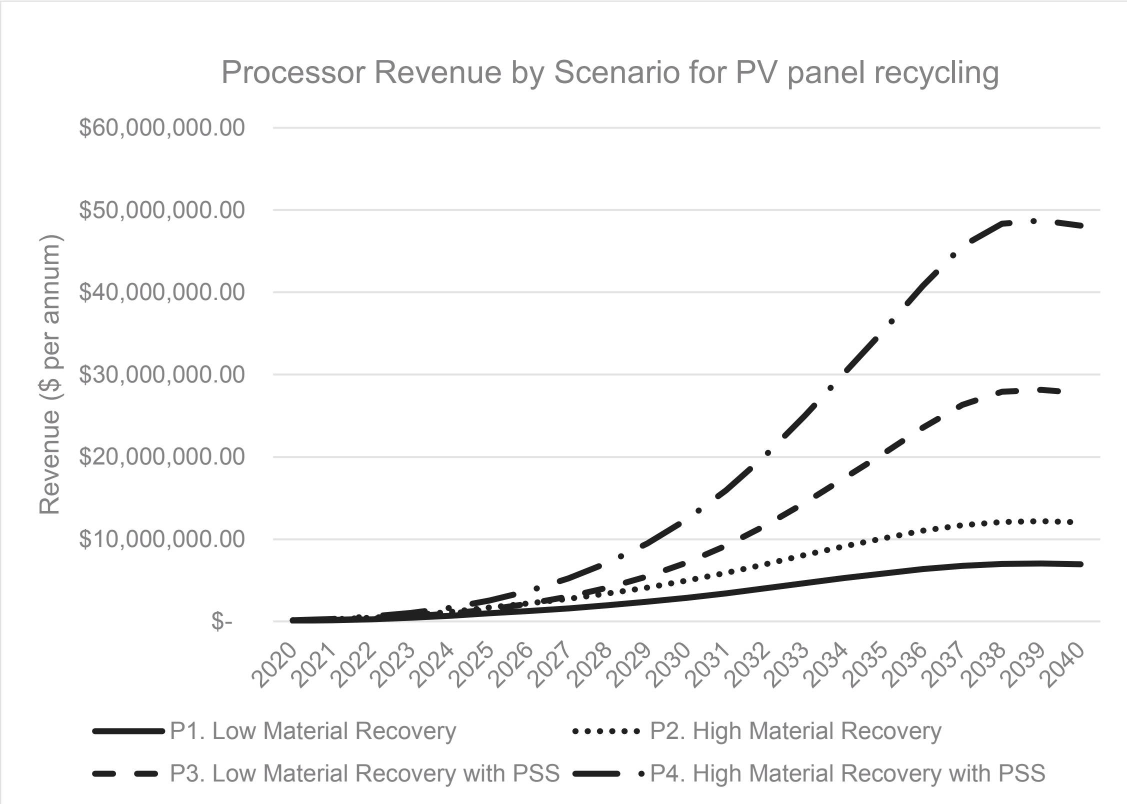


Figure 22: Processer revenue by scenario for PV panel recycling

Figure 22 shows that the high material recovery scenarios generate greater total revenue than the low recovery scenarios without product stewardship. The scenarios with product stewardship schemes generate greater revenue sooner because it is assumed that a product stewardship scheme will increase participation more quickly making greater volumes available for recovery.

The figure also shows the total potential revenue generated through PV collection and processing starts low but ramps up over time. This indicates that collection and processing is not economically feasible in the short term as it will not generate sufficient revenue or cash flow to be viable, but over time it can be a significant economic activity and presents a reasonable business opportunity. The figure also shows that, in the absence of an intervention such as product stewardship that assumes low expected participation rates, the total potential revenue reaches $10 million by 2035-36. If an intervention such as product stewardship incentivises higher participation, total revenue in NSW could reach $10 million by about 2029-30.

As noted on page 60, this assessment assumed glass to be valued at $0 per tonne. Therefore, glass would neither generate revenue nor impose disposal costs. The viability is sensitive to glass as it represents a large proportion of recovered materials, and therefore if all glass cannot be recovered and recycled it will impose a cost and impact viability.

Battery collection and processing total revenue in NSW

An assessment of the volumes of the waste batteries arising and the revenue that can be generated from gate fees and the sale of recovered commodities indicates the total revenue that PV panel recycling may generate over time. As Figure 23 shows, total revenue starts low due to the relatively small volumes of waste batteries and gradually increases.

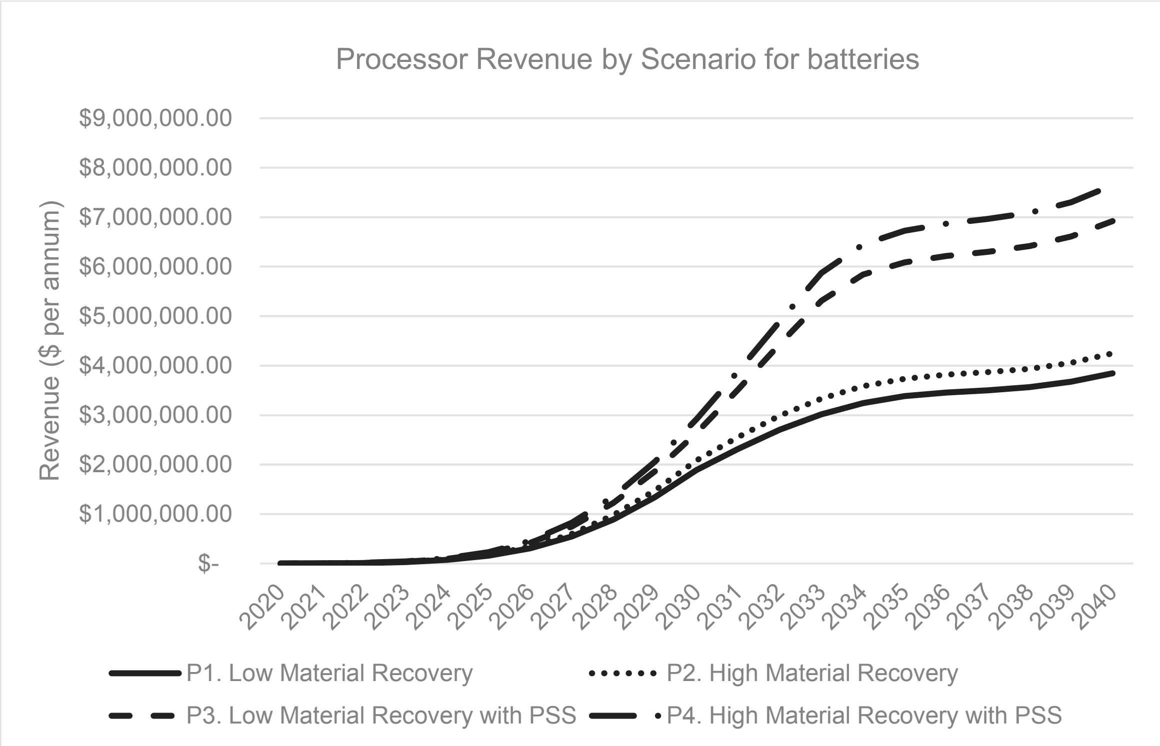


Figure 23: Processer revenue by scenario for batteries

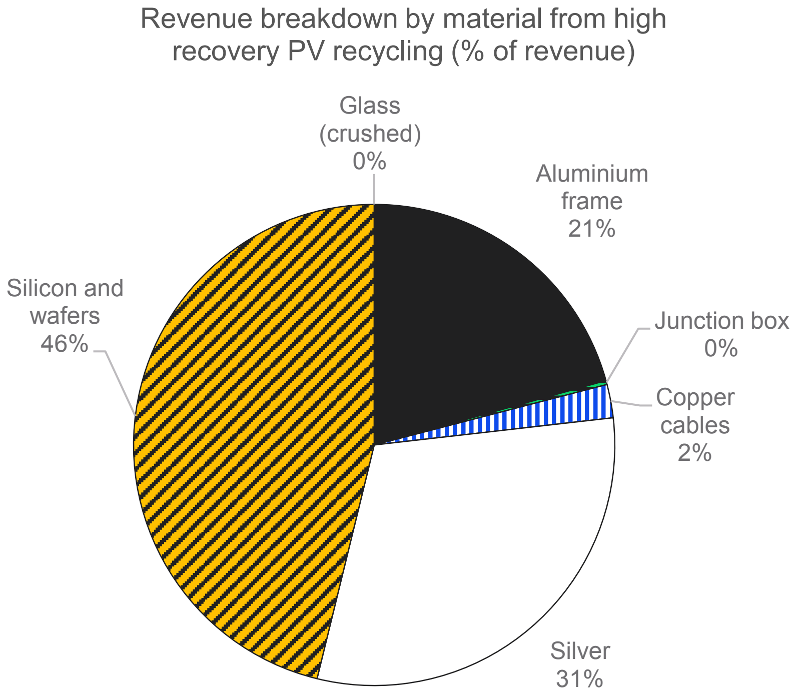
This assessment indicates that energy storage batteries alone are unlikely to be a significant recycling activity in terms of total potential revenue. However, it is noted that energy storage batteries are part of a range of different batteries from different sources that will be targeted for recovery and recycling, and so their economic viability is part of a bigger economic activity.

Figure 23 shows that the expected total revenue generated through battery collection and processing starts low but ramps up over time.

For all scenarios batteries investigated, energy storage batteries alone do not generate significant total revenue in NSW, potentially limited to $4-6 million by the mid 2030s (with or without intervention).

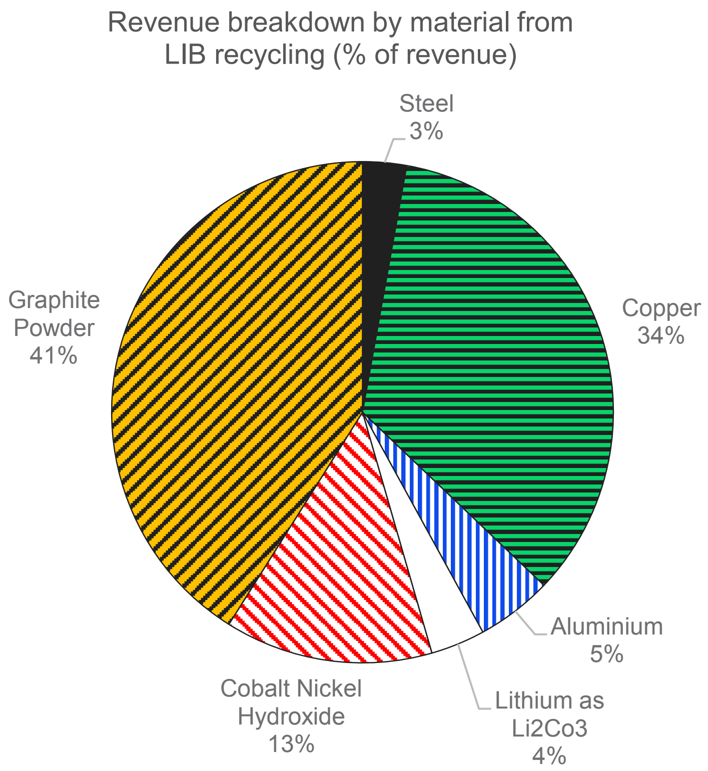
While this modelling indicates energy storage battery collection and recycling may be a minor economic activity, as noted above, on the basis that recovery will be part of a bigger collection and recycling activity it is expected that the recycling of energy storage batteries will be economically viable in NSW when these broader activities come on line.

PV Panels: Breakdown of Revenue by Material



- Glass is more than 65% by mass of the whole product
- Al recovery is the main target for low material recovery processors
- Metals are a significant contributor to revenue in both low and high recovery operations, they are in low volumes but have a high value
- Silicon and wafers are highly valuable
- For this study glass has been assumed to have $0 value, which assumes there is an end-market and it is not landfilled

Figure 24: Revenue breakdown by material from high recovery PV recycling



- Metals are recovered in both low and high material recovery processors and are of high value
- All materials recovered are valued with strong markets
- The so-called "black mass" from battery recycling is about 35% by weight in total and high material recovery processing extracts Li2Co3, cobalt nickel hydroxide and graphite powder, all of which have end-markets and are of high value

Figure 25: Revenue breakdown by material from LIB recycling

Implications of Findings

Currently, for both PV panels and batteries, the value of the commodities that can be recovered does not cover the processing costs and generate a margin for profit, necessitating a gate fee. In both cases, the high material recovery operations were predicted to achieve higher gross margins compared to the low recovery or initial processing pathways.

Although batteries are costly to collect and process, battery recycling is likely to need less support to be economically viable because collection of energy storage batteries in NSW will likely benefit from emerging recovery pathways for LIB from a range of other applications. Some streams of batteries are already managed by brand owners or manufacturers at end-of-life (particularly EV batteries where brand owners are motivated to protect technical knowledge) and a product stewardship approach to potentially manage all ESS is under active development (discussed further on the following page). Further, the market can charge high gate fees, and the recovered commodities (e.g. Cobalt, nickel) are of relatively high value, enabling higher margins to be achieved.

Both PV panels and batteries are in very low volumes for the short-to-medium term (up to five years), however product stewardship may increase participation rates and generate higher revenue sooner. The collection, reuse and recycling of PV panels is more likely to require intervention to be viable.

Product stewardship has been identified as being likely to lead to improved resource recovery and recycling of PV panels and batteries,[19] and a national product stewardship approach for PV panels is being actively considered, led by Sustainability Victoria in coordination with other Australian Governments. For batteries, the Queensland State Government is coordinating development of a scheme and has appointed the Battery Stewardship Council to progress a proposed stewardship approach intended to cover all battery types (except ULAB).

In this study, stakeholder interviews confirmed that there is an interest in product stewardship and an expectation that it can contribute to the economic viability of the collection and processing of PV panels, and that it may also assist with batteries.

With respect to economic viability in the NSW context, product stewardship is likely to assist by:

- Providing a coordinated pathway for collection and processing
- Financially supporting collection and processing
- Bringing forward participation rates (and therefore increase volumes available for collection and processing)
- Establishing industry standards for PV panel and battery collection and processing
- Promoting high recovery rates

For the purposes of this report, it was assumed that product stewardship will make PV panel collection and processing more economically viable especially by financially supporting collection and processing and bringing forward participation rates. The extent to which such benefits are achieved is ultimately dependent on the final design of any scheme(s).

Further Research Required

PV panels: with specific consideration to glass recovery - the most significant proportion of PV panels by mass - better understanding of the potential end markets and economics will help inform future policy and investments. Some stakeholders claim glass recovered from PV can go into high end markets (such as bottle making) however there are conflicting reports. Low material recovery processes that cannot liberate glass from the silicon wafers seems inconsistent with being able to recover the glass for further high-end use. High recovery pathways employing thermal technologies reportedly alter the glass and may limit opportunities for further processing. Overall, the pathways and fate of PV glass warrants more research.

Reuse pathways for PV panels also warrants further research. Insufficient information was available from stakeholders or existing reports to conduct a detailed economic assessment on the reuse of both PV panels and batteries. Stakeholders are actively investigating reuse options and developing business models. The development of such business models may benefit from support to research the key elements that are likely to influence a reuse pathway. Such elements include operational factors (such as dismantling requirements, handling and shipping and testing and redeployment specifications), regulatory issues and end-markets (local, interstate and international).

For the low recovery pathway, an inherent risk is observed in that reliance on low recovery pathways may undermine high recovery and more sustainable solutions. The high recovery pathway provides a better economic model as it can generate higher revenues through the recovery and sale of more commodities, but it needs higher volumes of throughput to be viable and achieve a reasonable return on investment. As noted, low recovery pathway is characterised by the removal of the Al frame from the PV panel and stockpiling the remainder while other technology solutions are developed and become feasible. The risk is that low recovery pathways – while perhaps necessary in the short term in the absence of other processing – may create stockpiles of material and may undermine investment in high recovery pathways by limiting access to volumes. The extent to which low recovery pathways may undermine the opportunity for high recovery investments in NSW, and therefore long-term sustainable solutions, remains unclear. As noted above, the glass recovery pathway warrants more research and further investigations may be required to understand whether interventions are required to ensure sustainable solutions are in place when needed.

Phase 5 References

1. R. Deng et al., Renewable and Sustainable Energy Reviews 109 (2019)
2. Lithium carbonate price 2010-2018 Published by M. Garside, Aug 9, 2019
3. IME/RWTH Aachen University estimates
4. PV Systems Stewardship Options Assessment, Prepared by Equilibrium for Sustainability Victoria, March 2019

Phase 6 – Funding Program Design

Objectives

The objective of this phase was to provide a summary of research findings (modelling and stakeholder research) considering the implications for program design and future research.

Approach

Drawing on research findings from Phases 1-5 and the stakeholder research, Phase 6 considered whether there is appetite for funding to support the reuse and recycling of PV panels and batteries from both an industry and research perspective. We sought specific feedback on the scope of funding and support that could accelerate existing initiatives and approaches to EOL management for PV panels and batteries.

Key stakeholders that were targeted included: PV and battery system manufacturers/importers, installers, e-waste collectors and recyclers, industry groups, government and research institutes.

Further desk top research and informal stakeholder discussions were undertaken to review what other government funding programs exist in this space and how they are structured and delivered.

Stakeholder Engagement

For Phase 6, stakeholder engagement complemented the stakeholder research from earlier Phases as well as the desk top research. There were 25 stakeholders identified and targeted in order to gather up-to-date data, insights and knowledge to assess the appetite for funding and inform considerations for scheme design.

this section on stakeholder consultation and findings has been removed for confidentiality reasons

Summary Findings

There is uncertainty about the quality of the recovered glass and available end markets

Phase 3 defined low and high recovery pathways to estimate the material recovery potential. For PV panels, the low recovery pathway that is being developed by recyclers/e-waste handlers in Australia can recover significant volumes; however, this assumes that the recovered glass meets market specifications. Stakeholders indicted that there is uncertainty about the quality of the recovered glass and a risk that the low recovery pathway could lead to stockpiling (Phase 4). Phase 5 illustrated that glass needs to be disposed of at no cost to improve economic viability. In the case of LIB, the initial processing pathway can divert significant volumes from landfill, however the high value metals are exported overseas.

The value of commodities that can be recovered does not cover processing costs (for PV panels and batteries)

Phase 5 assessed the economic viability of the different recovery pathways for PV panels and batteries using current data for the key financial elements for PV panel and battery recycling (including collection, handling and processing costs) obtained from market experts. For both PV panels and batteries, at present volumes, the value of the commodities that can be recovered does not cover the processing costs. For this reason, a gate fee is needed.

Stewardship approaches (government or industry-led) will be important to increase participation in recycling activities

In the case of PV panels, to cover capital costs and provide a return on investment within 2.5 years a low recovery facility would need about 1500 tonnes of PV panels per annum, and a high material recovery facility will need about 4500 tonnes per annum. Considering that total volumes in NSW could exceed 10,000 kt in 5 years (assuming 15-year lifespan – Phase 1) a low recovery facility would need to capture 15 % of this stream. Given the very low participation in recycling activities and the likelihood that there will be competition for the waste volumes, strategies to encourage participation in recycling schemes (e.g. Product stewardship) are needed to ensure enough volumes are available.

Other government funding programs provide limited insight to inform the design of the NSW program

Very few funding programs or interventions focussed on PV panel or battery recycling currently exist and those that do are new meaning they provide little insight for NSW at this time. The Australian Government through the Australian Renewable Energy Agency (ARENA) has launched a $15 million program for projects that can improve the economics of recycling through better upfront design, increased value of recovered materials and/or innovations for reusing recovered components in new PV panels. This fund that is now open for application targets R&D support for small-scale systems. South Australia is supporting research into options to improve EOL management of utility systems and infrastructure however no specific approach or funding has been announced.

the conclusions section has been removed for confidentiality reasons

Appendix: Risk ratings for recycling scenarios

Scenario 1 - Energy Storage systems, initial processing without product stewardship

	Green indicates that the factor identified is manageable or low risk with current technologies and systems
	Yellow indicates that technology or systems are conditionally feasible or medium risk when addressing the factor and that further development is needed
	Red indicates that the technology or systems are not currently feasible and are high risk when addressing the factor

Product Impacts And Aspects	**Source of Material Occurrence of waste material**	**Material Composition**	**Current and future volumes**	**Current Technology availability**	**Need to Create New Facilities**
Description	Sources of material being generated and market capacity/capability to collect the materials.	Risks associated with material composition and potential to cause harm to human health and the environment.	Volumes / amounts of material being generated and available.	Availability of technology for waste materials (up until 2035).	Market capability / capacity to process materials.
Risk Rating	**Low Risk** Industry confident on potential coverage, solar-connected systems part of wider battery recovery, reuse and recycling network and logistics	**Medium Risk** Known materials needing appropriate handling and management	**Low Risk** Industry confident on forecast for materials, solar-connected batteries and related energy storage systems part of wider battery recovery, reuse and recycling	**Low Risk** Technology available, becoming more mature and sustainable	**Medium Risk** Time lag for materials to present for recovery
Score	**1**	**2**	**2**	**1**	**2**
Evidence	Limited take back services at present (which reflects that it is a new technology and yet to reach end of life for some time). Take-back can be readily implemented via installers (which simplifies communication / logistics).	Contain hazardous / toxic material but only if released and unmanaged.	Very small volumes at present. Batteries storage consumption can be expected to grow significantly (but won't reach waste stream for some time). Collection/recycling will be subject to market factors.	Existing battery recycling infrastructure exists. Some service providers are collecting only then re-directing to battery recyclers (In NSW or VIC).	Subject to volumes and market share. Investment at present being delayed till market can justify the outlay.

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry standards
Description	Technology capability to recover materials or re-furbish systems.	Potential risks for local markets. Amount of material exported from Australia to other countries for re-use, re-furbishment, final treatment and disposal.	Downstream vendor regulations and management to ensure regulated and environmentally sound recycling and disposal of materials.	Potential for regulations to impact on resource recovery rates (e.g. Prescribed waste regulations, e-waste landfill ban).	Potential for standards to impact negatively the materials handling and removal standards (e.g. Clean Energy Council, Australian Standards).
Risk Rating	**Low Risk** Reasonable expected recovery rates about 70% +	**Medium risk** Internationally traded material. International conventions apply (Basel)	**Low risk** International conventions apply (Basel)	**Low Risk**	**Low Risk**
Score	**1**	**2**	**1**	**1**	**1**
Evidence	Existing technology and infrastructure for battery recycling can absorb energy storage batteries (both in terms of chemistry and volumes). Recovery rates in excess of 70%.	Some anecdotal evidence that batteries are being sent to Sri Lanka and India with PV panels (for sorting and re-use). Batteries fall under Basel Convention.	Not currently an issue except where AS/NZS5377 may be required.		

Scenario 2 - Energy Storage systems, recycling without product stewardship

Product Impacts and Aspects	**Source of Material Occurrence of waste material**	**Material Composition**	**Current and future volumes**	**Current Technology availability**	**Need to Create New Facilities**
Description	Sources of material being generated and market capacity/capability to collect the materials.	Risks associated with material composition and potential to cause harm to human health and the environment.	Volumes / amounts of material being generated and available.	Availability of technology for waste materials (up until 2035).	Market capability / capacity to process materials.
Risk Rating	**Low Risk** Industry confident on potential coverage, solar-connected systems part of wider battery recovery, reuse and recycling network and logistics	**Medium Risk** Known materials needing appropriate handling and management	**Medium Risk** Investment for local recycling higher cost and dependent on volumes	**Medium Risk** Facilities available but viability of local (NSW) sites unsure	**Medium Risk** Limited local processing capacity and capability
Score	1	2	2	2	2
Evidence	Limited take back services at present (which reflects that it is a new technology and yet to reach end of life for some time). Take-back can be readily implemented via installers (which simplifies communication / logistics).	Contain hazardous / toxic material but only if released and unmanaged.	Very small volumes at present. Batteries storage consumption can be expected to grow significantly (but won't reach waste stream for some time). Collection/recycling will be subject to market factors.	Existing battery recycling infrastructure exists and others may enter market if viable to do so. Technologies exist but limited presence in Australia.	Few if any exponents have capacity to achieve 95% recovery rate at NSW based plants.

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry standards
Description	Technology capability to recover materials or re-furbish systems.	Potential risks for local markets. Amount of material exported from Australia to other countries for re-use, re-furbishment, final treatment and disposal.	Downstream vendor regulations and management to ensure regulated and environmentally sound recycling and disposal of materials.	Potential for regulations to impacts on resource recovery rates (e.g. Prescribed waste regulations, e-waste landfill ban).	Potential for standards to impact negatively the materials handling and removal standards (e.g. Clean Energy Council, Australian Standards).
Risk Rating	**Medium Risk** Recovery rates for materials OK but will require investment to increase to 80% + or higher	**Medium Risk** Internationally traded material	**Low risk** International conventions apply (Basel)	**Low Risk**	**Low Risk**
Score	**2**	**2**	**1**	**1**	**1**
Evidence	Existing technology and infrastructure for battery recycling can absorb energy storage batteries (both in terms of chemistry and volumes) - . Investment likely to be required to achieve 95% recovery rate.	Some anecdotal evidence that batteries are being sent to Sri Lanka and India with PV panels (for sorting and re-use). Batteries fall under Basel Convention			Subject to review of AS3577

Scenario 3 - Energy Storage systems, initial processing with product stewardship

Product Impacts and Aspects	Source of Material Occurrence of waste material	Material Composition	Current and future volumes	Current Technology availability	Need to Create New Facilities
Description	Sources of material being generated and market capacity/capability to collect the materials.	Risks associated with material composition and potential to cause harm to human health and the environment.	Volumes / amounts of material being generated and available	Availability of technology for waste materials (up until 2035).	Market capability / capacity to process materials.
Risk Rating	**Low Risk** Industry confident on potential coverage, expectations that PS will directly or indirectly increase coverage and participation	**Medium Risk** Known materials needing appropriate handling and management	**Low risk** Likely PS will increase participation and coverage	**Low risk** PS may attract enhanced facilities	**Low risk** PS expected and likely to increase volumes and ramp up
Score	1	2	1	1	1
Evidence	Limited take back services at present (which reflects that it is a new technology and yet to reach end of life for some time). Take-back can be readily implemented via installers (which simplifies communication / logistics). The likelihood is that PS will improve collection rates.	Contain hazardous / toxic material but only if released and unmanaged	Very small volumes at present. Batteries storage consumption can be expected to grow significantly (but won't reach waste stream for some time). PSD scheme likely to improve collection services	Existing battery recycling infrastructure exists. Some service providers are collecting only then re-directing to battery recyclers (In NSW or VIC).	Subject to volumes and market share. Investment at present being delayed till market can justify outlay. PS likely to stimulate investment.

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry standards
Description	Technology capability to recover materials or re-furbish systems.	Potential risks for local markets. Amount of material exported from Australia to other countries for re-use, re-furbishment, final treatment and disposal.	Downstream vendor regulations and management to ensure regulated and environmentally sound recycling and disposal of materials.	Potential for regulations to impacts on resource recovery rates (e.g. Prescribed waste regulations, e-waste landfill ban).	Potential for standards to impact negatively the materials handling and removal standards (e.g. Clean Energy Council,

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry standards
					Australian Standards).
Risk Rating	**Low risk** No change with PS	**Medium Risk** Internationally traded material. International conventions apply (Basel)	**Low risk** International conventions apply (Basel)	**Low Risk**	**Low Risk**
Score	**1**	**2**	**1**	**1**	**1**
Evidence	Existing technology and infrastructure for battery recycling can absorb energy storage batteries (both in terms of chemistry and volumes). Recovery rates in excess of 70%	Some anecdotal evidence that batteries are being sent to Sri Lanka and India with PV panels (for sorting and re-use). Batteries fall under Basel Convention			

Scenario 4 - Energy Storage systems, recycling with product stewardship

Product Impacts and Aspects	Source of Material Occurrence of waste material	Material Composition	Current and future volumes	Current Technology availability	Need to Create New Facilities
Description	Sources of material being generated and market capacity/capability to collect the materials.	Risks associated with material composition and potential to cause harm to human health and the environment.	Volumes / amounts of material being generated and available	Availability of technology for waste materials (up until 2035).	Market capability / capacity to process materials.
Risk Rating	**Low Risk** Industry confident on potential coverage, expectations that PS will directly or indirectly increase coverage and participation	**Medium Risk** Known materials needing appropriate handling and management	**Low risk** Investment for local recycling more likely with PS	**Low Risk** Facilities available and PS expected to support viability of local (NSW) sites	**Medium Risk** Limited local processing capacity and capability
Score	**1**	**2**	**1**	**1**	**2**

Product Impacts and Aspects	Source of Material Occurrence of waste material	Material Composition	Current and future volumes	Current Technology availability	Need to Create New Facilities
Evidence	Limited take back services at present (which reflects that it is a new technology and yet to reach end of life for some time). Take-back can be readily implemented via installers (which simplifies communication / logistics). The likelihood is that PS will improve collection rates.	Contain hazardous / toxic material but only if released and unmanaged.	Very small volumes at present. Batteries storage consumption can be expected to grow significantly (but won't reach waste stream for some time). PSD scheme likely to improve collection services.	Existing battery recycling infrastructure exists. Some service providers are collecting only then re-directing to battery recyclers (In NSW or VIC).	Subject to volumes and market share. Investment at present being delayed till market can justify the outlay. PS likely to stimulate investment.

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry Standards
Description	Technology capability to recover materials or re-furbish systems.	Potential risks for local markets. Amount of material exported from Australia to other countries for re-use, re-furbishment, final treatment and disposal.	Downstream vendor regulations and management to ensure regulated and environmentally sound recycling and disposal of materials.	Potential for regulations to impacts on resource recovery rates (e.g. Prescribed waste regulations, e-waste landfill ban).	Potential for standards to impact negatively the materials handling and removal standards (e.g. Clean Energy Council, Australian Standards).
Risk Rating	**Medium Risk** Recovery rates for materials OK but will require investment to increase to 80% + or higher	**Medium risk** Internationally traded material.	**Low risk** International conventions apply (Basel)	**Low Risk**	**Low Risk**
Score	**2**	**2**	**1**	**1**	**1**
Evidence	Existing technology and infrastructure for battery recycling can absorb energy storage batteries (both in	Some anecdotal evidence that batteries are being sent to Sri Lanka and India with PV panels (for sorting and			

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry Standards
	terms of chemistry and volumes) but recovery of 95% not likely without upgrade.	re-use). Batteries fall under Basel Convention.			

Scenario 5 - Photovoltaic / PV panels, low material recovery without product stewardship

Product Impacts and Aspects	Source of Material Occurrence of waste material	Material Composition	Current and future volumes	Current Technology availability	Need to Create New Facilities
Description	Sources of material being generated and market capacity/capability to collect the materials.	Risks associated with material composition and potential to cause harm to human health and the environment.	Volumes / amounts of material being generated and available.	Availability of technology for waste materials (up until 2035).	Market capability / capacity to process materials.
Risk Rating	**High Risk** No collection systems established to collect PV PV panels and very limited take-back services offered or marketed. Limited or no consumer awareness of need to reuse or recycle PV panels and therefore no incentive to collect at present.	**Medium Risk** Some PV panels can contain hazardous and/or toxic materials which if not safely recovered and managed can harm human health.	**Low Risk** Current volumes of PV panel waste are low but growing with projections indicating significant increases of waste arising.	**High Risk** Current technology, processes and methods available in NSW are very limited verging on non-existent.	**Medium Risk** Current projections indicate increasing demand for processing alternatives (including downcycling) other than landfilling. Current providers and those planning to enter the market require significantly increased volumes to justify investment in creating new facilities with an acceptable ROI.
Score	**3**	**2**	**1**	**3**	**2**
Evidence	Current waste arising results from decommissioned eol PV panels upon installation of new PV panels. Minimal consumer awareness and associated incentives to recycle eol PV panels.	Some stakeholders believe certain substances used in manufacturing PV panels can pose a hazard, but their safe management is determined by specific processing method / technology.	Relatively small volumes of PV panel waste arising currently however volumes are projected to grow significantly over the next decade.	End-to-end processing technology for the complete PV panel in NSW appears non-existent at present. Limited pre-treatment (manual or mechanical) is taking place with a focus on removing Al frames and inverters for further processing through other methods and technologies.	Current capability and capacity appears very limited with no evidence of any existing facilities in NSW that are dedicated to PV panels with the exception of some minor collection/stockpiling activity. Projected future volumes suggest a significant increase in both capability and capacity is required in NSW.

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry standards
Description	Technology capability to recover materials or re-furbish systems.	Potential risks for local markets. Amount of material exported from Australia to other countries for re-use, re-furbishment, final treatment and disposal.	Downstream vendor regulations and management to ensure regulated and environmentally sound recycling and disposal of materials.	Potential for regulations to impacts on resource recovery rates (e.g. Prescribed waste regulations, e-waste landfill ban).	Potential for standards to impact negatively the materials handling and removal standards (e.g. Clean Energy Council, Australian Standards).
Risk Rating	**High Risk** Data and information to date highlights limited or non-existent technology, processes and methods to recover and downcycle materials from PV panels and/or refurbishment and reuse them.	**Low Risk** Not applicable at this time. Some eol PV panels being exported for reuse in very small numbers.	**Low Risk** Not applicable at this time, or demanded by the market/consumers or government.	**Low Risk** Not applicable at this time but may change subject to future landfill bans, stockpiling regulations and/or regulated stewardship programs.	**Low Risk** Not applicable at this time, or demanded by the market/consumers or government.
Score	**3**	**1**	**1**	**1**	**1**
Evidence	Evidence indicates that PV panel waste is currently being landfilled with some stockpiling underway for future processing. Al frames and inverters recovered for conventional processing and on-sale. No evidence of PV panel refurbishment and reuse in NSW at present. Some evidence and intent of new refurb, reuse and recycling services being developed at present specifically for PV panels in NSW however they are yet to be commercialised or actively marketed.	No evidence of any significant exports; however some anecdotal commentary about very small numbers of working second-life PV panels being shipped to developing countries and Oceania nations for reuse.	No evidence of any tracking systems for exports.	Ongoing evolution/expansion of national waste export ban may impact on materials recovered from PV panels. Future landfill bans in NSW may also be relevant. Regulations concerning stockpiling may also be pertinent.	There is no dedicated standard applicable to PV panels being used in Australia however AS5377 (ewaste) ewaste is partly relevant and could be applied.

Scenario 6 - Photovoltaic / PV panels, recycling without product stewardship

Product Impacts and Aspects	Source of Material Occurrence of waste material	Material Composition	Current and future volumes	Current Technology availability	Need to Create New Facilities
Description	Sources of material being generated and market capacity/capability to collect the materials.	Risks associated with material composition and potential to cause harm to human health and the environment.	Volumes / amounts of material being generated and available.	Availability of technology for waste materials (up until 2035).	Market capability / capacity to process materials.
Risk Rating	**High Risk** No collection systems established to collect PV panels and very limited take-back services offered or marketed. Limited or no consumer awareness of need to reuse or recycle PV panels and therefore no incentive to collect at present.	**Medium Risk** Some PV panels can contain hazardous and/or toxic materials which if not safely recovered and managed can harm human health. Appropriate technology may deliver increased upcycling performance.	**Low Risk** Current volumes of PV panel waste are low but growing with projections indicating significant increases of waste arising. Appropriate technology may deliver increased upcycling performance.	**High Risk** Current technology, processes and methods available in NSW are very limited verging on non-existent. Appropriate technology may deliver increased upcycling performance.	**Medium Risk** Current projections indicate increasing demand for processing alternatives (including upcycling) other than landfilling. Current providers and those planning to enter the market require significantly increased volumes to justify investment in creating new facilities with an acceptable ROI.
Score	3	2	1	3	2
Evidence	No collection systems established and very limited take-back services. Current waste arising results from decommissioned eol PV panels upon installation of new PV panels. Minimal consumer awareness and associated incentives to recycle eol PV panels.	Some PV panels can contain hazardous and/or toxic material. Harm to human health subject to processing method/technology. Subject to local business investment, more advanced processing technologies from Europe and Japan may improve safe recovery and management of hazardous and/or toxic substances.	Relatively small volumes of PV panel waste arising currently however volumes are projected to grow significantly over the next decade. Existing and emerging service providers (PV panel recyclers/refurbishers) believe future volumes are	End-to-end processing technology for the complete PV panel in NSW appears non-existent at present. Limited pre-treatment (manual or mechanical) is taking place with a focus on removing Al frames and inverters for further processing through other methods and technologies. Existing and emerging service providers (esp. PV panel recyclers) believe that more advanced processing technologies from Europe or Japan have the potential to	Current capability and capacity appears very limited with no evidence of any existing facilities in NSW that are dedicated to PV panels with the exception of some minor collection/stockpiling activity. Projected future volumes suggest a significant increase in both capability and capacity is required in NSW.

Product Impacts and Aspects	Source of Material Occurrence of waste material	Material Composition	Current and future volumes	Current Technology availability	Need to Create New Facilities
			likely to increase dramatically and improve investment confidence related to new plant and equipment.	increase material recovery rates and extract metals and materials not currently captured.	

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry standards
Description	Technology capability to recover materials or re-furbish systems.	Potential risks for local markets. Amount of material exported from Australia to other countries for re-use, re-furbishment, final treatment and disposal.	Downstream vendor regulations and management to ensure regulated and environmentally sound recycling and disposal of materials.	Potential for regulations to impacts on resource recovery rates (e.g. Prescribed waste regulations, e-waste landfill ban).	Potential for standards to impact negatively the materials handling and removal standards (e.g. Clean Energy Council, Australian Standards).
Risk Rating	**High Risk** Data and information to date highlights limited or non-existent technology, processes and methods to recover and upcycle materials from PV panels and/or refurbishment and reuse them.	**Low Risk** Not applicable at this time. Some eol PV panels being exported for reuse in very small numbers.	**Low Risk** Not applicable at this time or demanded by the market/consumers or government.	**Low Risk** Not applicable at this time but may change subject to future landfill bans, stockpiling regulations and/or regulated stewardship programs.	**Low Risk** Not applicable at this time or demanded by the market/consumers or government.

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry standards
Score	**3**	**1**	**1**	**1**	**1**
Evidence	No evidence of PV panel refurbishment and reuse in NSW at present. Some evidence and intent of new refurb, reuse and recycling services being developed at present specifically for PV panels in NSW however they are yet to be commercialised or actively marketed. Evidence indicates that PV panel waste is currently being landfilled with some stockpiling underway for future processing. Al frames and inverters recovered for conventional processing and on-sale. No evidence of any exports related to materials for upcycling.	No evidence of any significant exports related to materials for upcycling; however some anecdotal commentary about very small numbers of working second-life PV panels being shipped to developing countries and Oceania nations for reuse. No evidence of exporting materials for upcycling.	No evidence of any tracking systems for exports.	Ongoing evolution/expansion of national waste export ban may impact on materials recovered from PV panels. Future landfill bans in NSW may also be relevant. Regulations concerning stockpiling may also be pertinent.	There is no dedicated standard applicable to PV panels being used in Australia however AS5377 (ewaste) ewaste is partly relevant and could be applied.

Scenario 7 - Photovoltaic / PV panels, initial processing with product stewardship

Product Impacts and Aspects	Source of Material Occurrence of waste material	Material Composition	Current and future volumes	Current Technology availability	Need to Create New Facilities
Description	Sources of material being generated and market capacity/capability to collect the materials.	Risks associated with material composition and potential to cause harm to human health and the environment.	Volumes / amounts of material being generated and available.	Availability of technology for waste materials (up until 2035).	Market capability / capacity to process materials.
Risk Rating	**Medium Risk** A subsidised stewardship program starts to create certainty, build market confidence and help establish collection systems. Growing consumer awareness of need to reuse or recycle PV PV panels will build incentive to collect and dispose of responsibly.	**Medium Risk** A subsidised stewardship program may have the resources and resulting technologies, processes and methods to safely recover and manage any hazardous and/or toxic substances found in some PV panels.	**Low Risk** While current volumes of PV panel waste are low, a subsidised stewardship program will grow consumer awareness and stimulate higher levels of collection activity which is likely to secure increased volumes being recycled for materials downcycling.	**Low Risk** While current technology, processes and methods available in NSW are very limited, a subsidised stewardship program can support infrastructure investment and development.	**Medium Risk** A subsidised stewardship program is likely to underpin increased investment in new facilities as well as grow market confidence. This can directly build capability and capacity related to processing PV panels for reuse, refurb and recycling.
Score	2	2	1	1	2
Evidence	Subsidised collection via a stewardship program would increase disposal options for installers, solar farms, commercial installations and residential consumers. Installers are well placed to utilise a subsidised collection option which in turn would likely increase collection rates.	Some PV panels can contain hazardous and/or toxic material. A subsidised stewardship program may provide the funds and incentives for providers to ensure improved processing methods/technologies to improve safe recovery and management of hazardous and/or toxic substances.	Relatively small volumes of PV panel waste arising currently however a subsidised stewardship program is likely to provide resources and incentives to improve collection services and therefore recover increased volumes.	End-to-end processing technology for the complete PV panel in NSW appears non-existent at present. Limited downcycling and pre-treatment (manual or mechanical) is taking place with a focus on removing Al frames and inverters for further processing through other methods and technologies. A	Current capability and capacity appears very limited with no evidence of any existing facilities in NSW that are dedicated to PV panels with the exception of some minor collection/stockpiling activity. A subsidised stewardship program may provide resources and incentives for providers to purchase/invest in more advanced technology from Europe or Japan or commercialise local

				subsidised stewardship program may provide resources and incentives for providers to purchase/invest in more advanced technology from Europe or Japan or commercialise local R&D eg. UNSW, Deakin University.	R&D eg. UNSW, Deakin University.

Product Impacts and Aspects	Resource recovery / landfill diversion	Overseas exports - amount exported (%)	End use of overseas exports - maturity of tracking system	Jurisdictional Regulations	Industry standards
Description	Technology capability to recover materials or re-furbish systems.	Potential risks for local markets. Amount of material exported from Australia to other countries for re-use, re-furbishment, final treatment and disposal.	Downstream vendor regulations and management to ensure regulated and environmentally sound recycling and disposal of materials.	Potential for regulations to impacts on resource recovery rates (e.g. Prescribed waste regulations, e-waste landfill ban).	Potential for standards to impact negatively the materials handling and removal standards (e.g. Clean Energy Council, Australian Standards).
Risk Rating	**Low Risk** A subsidised stewardship program can provide the investment, confidence and wider industry awareness necessary to maximise resource recovery opportunities and improve technology capability. Incremental activity starting with materials downcycling is likely and/or	**Low Risk** Not applicable at this time, however a subsidised stewardship program funded by oems and manufacturers may introduce specific requirements related to extent of in-country processing versus export.	**Low Risk** Not applicable at this time, however a subsidised stewardship program funded by oems and manufacturers may introduce specific requirements related downstream tracking and assurance measures in general.	**Low Risk** Not applicable at this time but may change subject to future landfill bans, stockpiling regulations. A subsidised stewardship program that is regulated may bring increased certainty, confidence and transparency to the wider industry, consumers and all levels of government.	**Low Risk** A subsidised stewardship program funded by oems and manufacturers is likely to involve adherence to relevant standards or the creation of new dedicated standards. A regulated stewardship program may 'call-up' specific standards with a view to maintaining certain

	subject to market factors and commodity values.				performance standards related to environmental management and workplace safety.
Score	**1**	**1**	**1**	**1**	**1**
Evidence	No evidence of PV panel refurbishment and reuse in NSW at present. Some evidence and intent of new refurb, reuse and recycling services being developed at present specifically for PV panels in NSW. A subsidised stewardship program may provide resources and incentives for providers to purchase/invest in more advanced technology from Europe or Japan, or commercialise local R&D eg. UNSW, Deakin University. Al frames and inverters recovered for conventional processing and on-sale. No evidence of any exports related to materials for upcycling.	No evidence of any significant exports related to materials for downcycling, however a subsidised stewardship program may create the incentives or finance the technology needed and identify potential new markets overseas.	No evidence of any tracking systems for exports. A subsidised stewardship program involving oems, brands and PV panel manufacturers may provide the incentive and 'customer' requirement to develop and implement effective tracking and assurance systems.	A coregulated or mandatory scheme under the Commonwealth Product Stewardship Act (or equivalent NSW scheme) would likely have a positive impact on resource recovery performance across the entire product category. Ongoing evolution/expansion of national waste export ban may impact on materials recovered from PV panels. Future landfill bans in NSW may also be relevant. Regulations concerning stockpiling may also be pertinent.	There is no dedicated standard applicable to PV panels being used in Australia however AS5377 (ewaste) ewaste is partly relevant and could be applied. A subsidised stewardship program involving oems, brands and PV panel manufacturers may provide the incentive and 'customer' requirement to develop and implement specific standards relevant to PV panels and/or PV panel systems.

Scenario 8 - Photovoltaic / PV PV panels, high material recovery with product stewardship

Product Impacts and Aspects	Source of Material Occurrence of waste material	Material Composition	Current and future volumes	Current Technology availability	Need to Create New Facilities
Description	Sources of material being generated and market capacity/capability to collect the materials.	Risks associated with material composition and potential to cause harm to human health and the environment.	Volumes / amounts of material being generated and available.	Availability of technology for waste materials (up until 2035).	Market capability / capacity to process materials.
Risk Rating	**Medium Risk** A subsidised stewardship program starts to create certainty, build market confidence and help establish collection systems. Growing consumer awareness of need to reuse or recycle PV panels will build incentive to collect and dispose of responsibly.	**Medium Risk** A subsidised stewardship program may have the resources and resulting technologies, processes and methods to safely recover and manage any hazardous and/or toxic substances found in some PV panels. This is likely if there is an emphasis on upcycling outcomes.	**Low Risk** While current volumes of PV panel waste are low, a subsidised stewardship program will grow consumer awareness and stimulate higher levels of collection activity which is likely to secure increased volumes being recycled for materials upcycling.	**Low Risk** While current technology, process and methods available in NSW are very limited, a subsidised stewardship program can support infrastructure investment and development. This is likely if there is an emphasis on upcycling outcomes.	**Medium Risk** A subsidised stewardship program is likely to underpin increased investment in new facilities as well as grow market confidence. This can directly build capability and capacity related to processing PV panels for reuse, refurb and recycling.
Score	**2**	**2**	**1**	**1**	**2**
Evidence	Subsidised collection via a stewardship program would increase disposal options for installers, solar farms, commercial installations and residential consumers. Installers are well placed to utilise a subsidised collection option which in turn would likely increase collection rates.	Some PV panels can contain hazardous and/or toxic material. A subsidised stewardship program may provide the funds and incentives for providers to ensure improved processing methods/technologies to improve safe recovery and management of hazardous and/or toxic substances.	Relatively small volumes of PV panel waste arising currently however a subsidised stewardship program is likely to provide resources and incentives to improve collection services and therefore recover increased volumes.	End-to-end processing technology for the complete PV panel in NSW appears non-existent at present. Limited downcycling and pre-treatment (manual or mechanical) is taking place with a focus on removing Al frames and inverters for further processing through other methods and technologies. A subsidised stewardship program may provide resources and incentives for	Current capability and capacity appears very limited with no evidence of any existing facilities in NSW that are dedicated to PV panels with the exception of some minor collection/stockpiling activity. A subsidised stewardship program may provide resources and incentives for providers to purchase/invest in more advanced technology from Europe or Japan, or

				providers to purchase/invest in more advanced technology from Europe or Japan, or commercialise local R&D eg. UNSW, Deakin University.	commercialise local R&D eg. UNSW, Deakin University.

Product Impacts and Aspects	**Resource recovery / landfill diversion**	**Overseas exports - amount exported (%)**	**End use of overseas exports - maturity of tracking system**	**Jurisdictional Regulations**	**Industry standards**
Description	Technology capability to recover materials or re-furbish systems.	Potential risks for local markets. Amount of material exported from Australia to other countries for re-use, re-refurbishment, final treatment and disposal.	Downstream vendor regulations and management to ensure regulated and environmentally sound recycling and disposal of materials.	Potential for regulations to impacts on resource recovery rates (e.g. Prescribed waste regulations, e-waste landfill ban).	Potential for standards to impact negatively the materials handling and removal standards (e.g. Clean Energy Council, Australian Standards).
Risk Rating	**Low Risk** A subsidised stewardship program can provide the investment, confidence and wider industry awareness necessary to maximise resource recovery opportunities and improve technology capability. This is likely if there is an emphasis on upcycling outcomes. Always subject to market factors and commodity values.	**Low Risk** Not applicable at this time, however a subsidised stewardship program funded by oems and manufacturers may introduce specific requirements related to extent of in-country processing versus export.	**Low Risk** Not applicable at this time, however a subsidised stewardship program funded by oems and manufacturers may introduce specific requirements related downstream tracking and assurance measures in general. This is likely if there is an emphasis on upcycling outcomes.	**Low Risk** Not applicable at this time but may change subject to future landfill bans, stockpiling regulations. A subsidised stewardship program that is regulated may bring increased certainty, confidence and transparency to the wider industry, consumers and all levels of government.	**Low Risk** A subsidised stewardship program funded by oems and manufacturers is likely to involve adherence to relevant standards or the creation of new dedicated standards. A regulated stewardship program may 'call-up' specific standards with a view to maintaining certain performance standards related to environmental management and workplace safety.
Score	**1**	**1**	**1**	**1**	**1**

Evidence	No evidence of PV panel refurbishment and reuse in NSW at present. Some evidence and intent of new refurb, reuse and recycling services being developed at present specifically for PV panels in NSW. A subsidised stewardship program may provide resources and incentives for providers to purchase/invest in more advanced technology from Europe or Japan, or commercialise local R&D eg. UNSW, Deakin University. Al frames and inverters recovered for conventional processing and on-sale. No evidence of any exports related to materials for upcycling.	No evidence of any significant exports related to materials for downcycling, however a subsidised stewardship program may create the incentives or finance the technology needed and identify potential new markets overseas.	No evidence of any tracking systems for exports. A subsidised stewardship program involving oems, brands and PV panel manufacturers may provide the incentive and 'customer' requirement to develop and implement effective tracking and assurance systems.	A coregulated or mandatory scheme under the Commonwealth Product Stewardship Act (or equivalent NSW scheme) would likely have a positive impact on resource recovery performance across the entire product category. Ongoing evolution/expansion of national waste export ban may impact on materials recovered from PV panels. Future landfill bans in NSW may also be relevant. Regulations concerning stockpiling may also be pertinent.	There is no dedicated standard applicable to PV panels being used in Australia however AS5377 (ewaste) ewaste is partly relevant and could be applied. A subsidised stewardship program involving oems, brands and PV panel manufacturers may provide the incentive and 'customer' requirement to develop and implement specific standards relevant to PV panels and/or PV panel systems.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