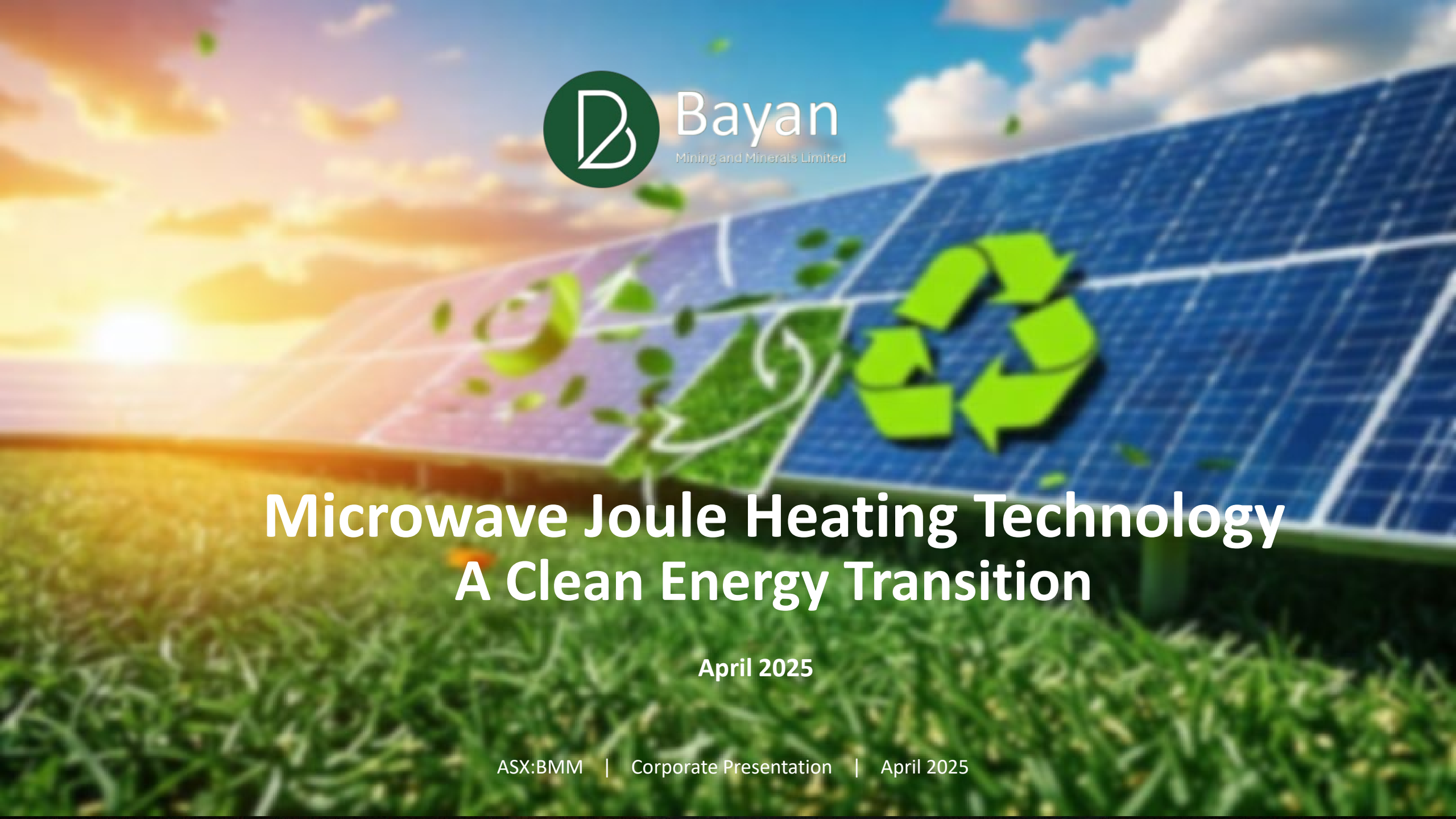

Bayan
Mining and Minerals Limited

Microwave Joule Heating Technology
A Clean Energy Transition

April 2025

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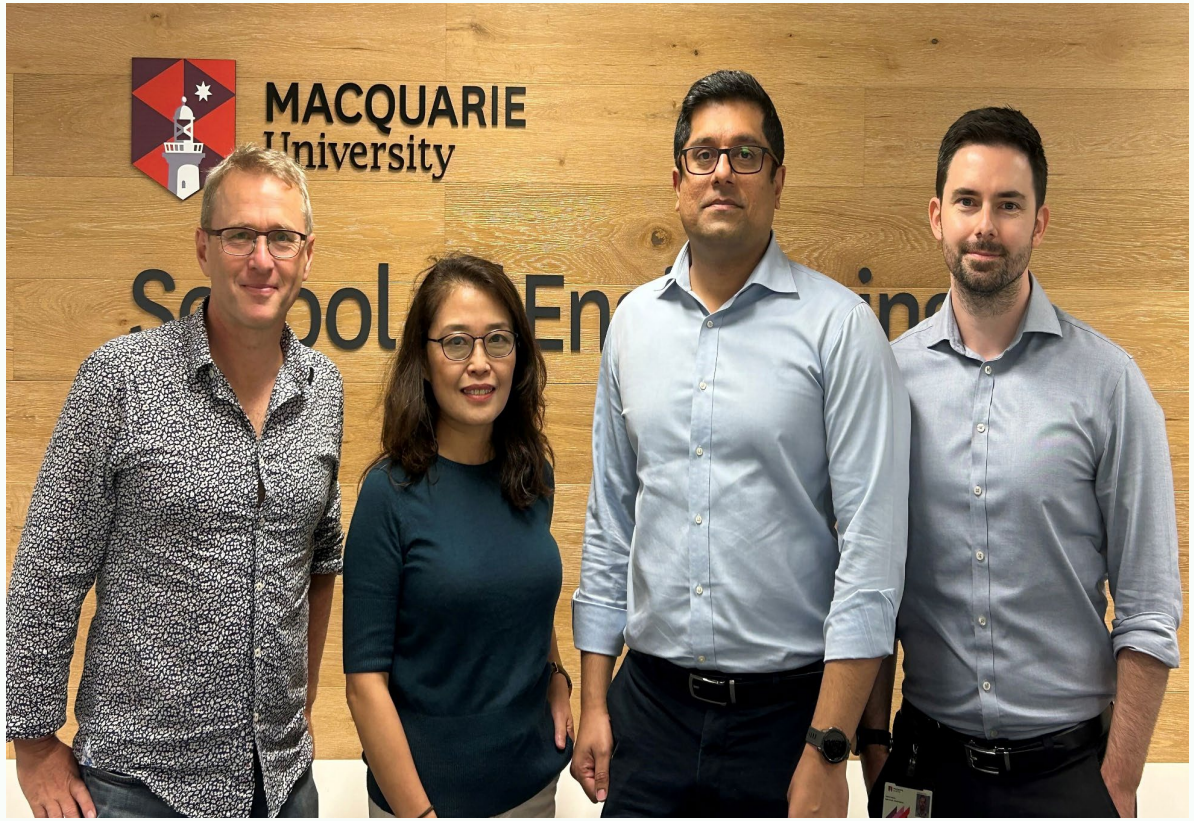
New Technology To Improve Recycling

Microwave technology invented at Macquarie University will improve the manufacture of solar cells and make them easier to recycle.



The research team comprised (from left to right) Professor Darren Bagnall, Professor Shujuan Huang, Dr Binesh Puthen Veettil and Dr David Payne

- **Patented Innovation**: A family of patents have been secured from Macquarie University, covering both Australia and the United States.
- **Academic & Government Backing**: Led by Dr. Binesh Puthen Veettil, this technology was developed in collaboration with the School of Photovoltaics at UNSW, with initial funding from the Australian Centre for Advanced Photovoltaics. It has since gained further support from the Australian Renewable Energy Agency (ARENA), highlighting its strategic importance in the clean energy sector.
- **Microwave-Based Recycling**: This technology utilises microwave radiation to selectively heat silicon, while leaving materials like glass, silver, and aluminum largely unaffected. This precision heating allows for rapid and energy efficient processing without the use of toxic chemicals, making it a cleaner and more sustainable recycling solution.
- **Sustainable Silicon Recovery**: By enabling the quick and cost-effective separation of silicon from laminated solar panels, this innovation provides an environmentally friendly solution for recycling solar panels and electronic waste, supporting the semiconductor industry and the critical mineral supply chain.

New technology advances solar-cell production | The Lighthouse

Market Overview

Market Trends Driving the Future of Clean Energy and Resource Recovery

Market Potential	By 2035, Australia alone is projected to accumulate 1 million tones of end-of-life solar panels, with a total recoverable material value exceeding $1 billion[1]
Untapped Economic Value	By 2045, Australia could dispose of 34.6 GW of fully serviceable solar panels, representing an economic opportunity[2]
Changing Geopolitical Landscape	Dumping solar panels in landfills was once the cheapest option, but growing clean energy demand makes sustainable recycling more urgent

The global transition to renewable energy has driven exponential growth in solar power adoption, with photovoltaic (PV) panels becoming a cornerstone of clean energy production

1,2. Recycling Wind Turbines, Solar Panels and Batteries: Fact Sheet | Clean Energy Council

Solar Panel Recycling Facts

Rising Demand and Urgent Need for Sustainable Recycling Solutions

15%

Currently only 15% of Solar Panels are recycled in Australia and Worldwide

18X

The amount of e-waste created from solar PV is forecast to increase 18x by 2030

$57B

The global economy suffers a loss of at least US$57 billion every year due to the disposal of valuable raw materials like Silicon, Gallium, Indium and Silver that could otherwise be recovered through proper recycling

The economic impacts of e-waste - Sircel

Valuable Minerals Lost From Inefficient Recycling Practices

Silicon

Key material in solar panels, acting as the semiconductor that transforms sunlight into electricity.

Silver

Essential for high-efficiency solar panels due to its superior electrical conductivity

Gallium

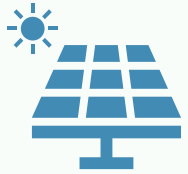
Key material in solar cells and LEDs, enhancing energy efficiency

Indium

Used in thin-film solar panels for improved energy absorption and efficiency

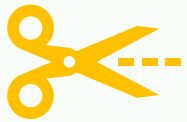
Inefficiencies In Traditional Solar Panel Recycling

Once a panel has reached its 20-25 year life span, its components should be recycled.
Currently, the end-of-life solar panels are first crushed, and the raw materials are extracted by thermal and chemical processes. This is because of the difficulty in separating the solar cells from the Front Glass and ethylene vinyl acetate (EVA).



Initial Dismantling

Solar panels are dismantled to separate key components such as the glass, aluminium frame, and internal layers for further processing.



Mechanical Breakdown

The separated materials are then crushed and shredded into smaller fragments, preparing them for material recovery

Material Extraction

Conventional processes often down-cycle silicon and glass, reducing purity and limiting their reuse value in high-performance applications.

Delaminating Solar Cells

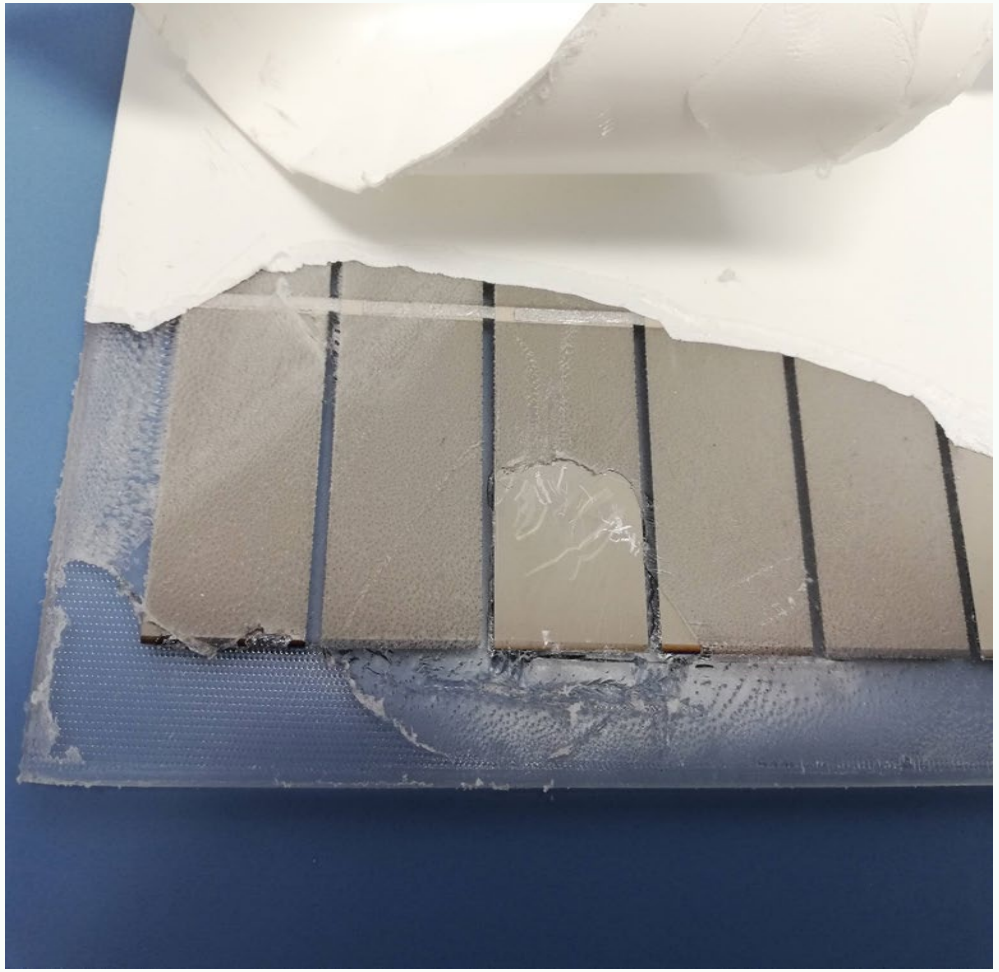
Revolutionising Solar Panel Recycling with Microwave Technology

Traditional solar panel fabrication requires high-temperature annealing in ovens, consuming significant energy.

A proof of concept has been achieved by Macquarie University for the ***Delaminating and laminating of photovoltaic modules and solar cells*** *using* ***Microwave Joule Heating Technology*** that enables targeted heating of silicon, softening the ethylene vinyl acetate (EVA) layer that protects the silicon plate.

This allows for mechanical peeling of the EVA layer, enabling easy delamination and recovery of valuable components.

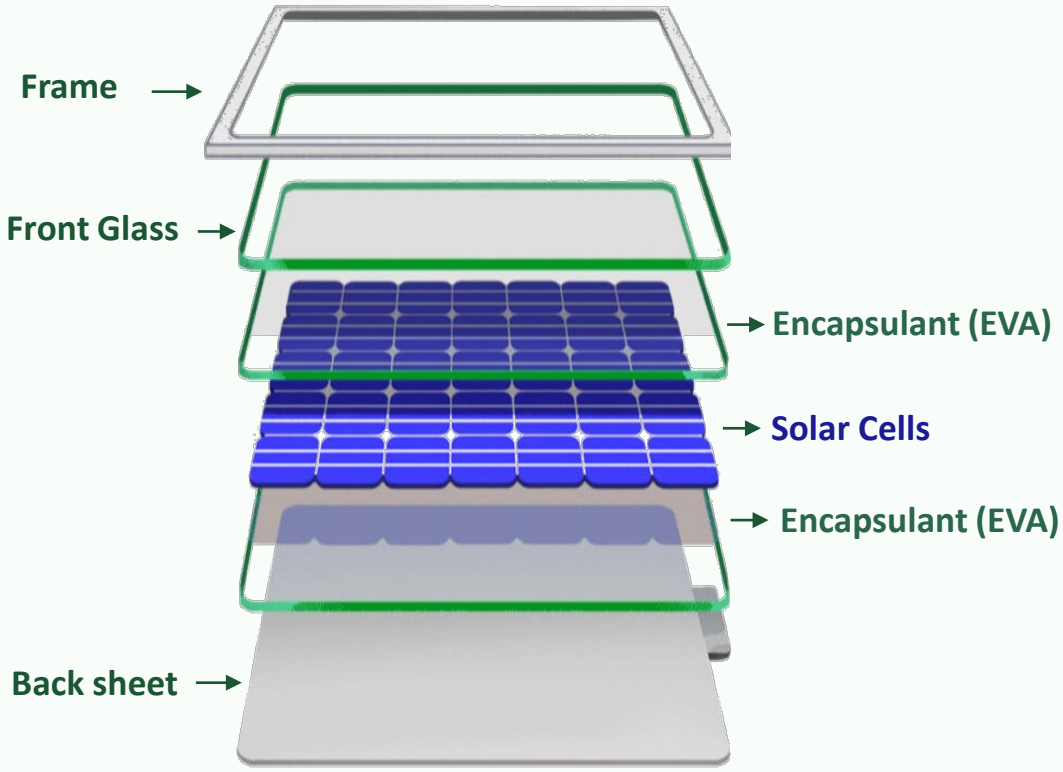
Unlike traditional recycling methods that involve crushing panels, extreme heat (1400°C), and chemical treatments, this process is energy-efficient and environmentally friendly.



How Does it Work?

The Power of Microwave Delamination

Solar Panel

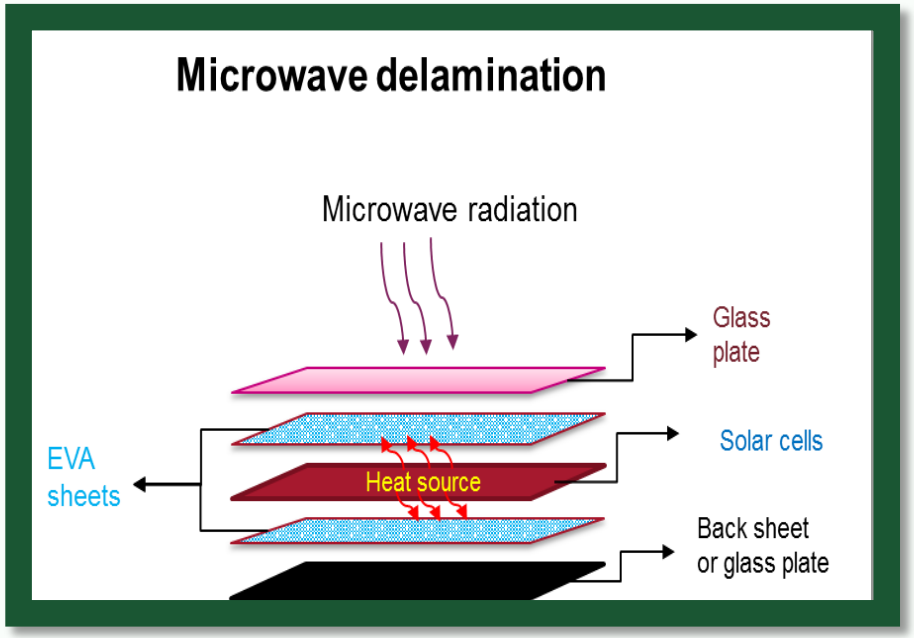


Microwave Joule Heating Technology

- Microwave energy targets silicon cells, rapidly heating them while keeping surrounding materials cool.
- The EVA plastic layer softens and degrades, allowing easy separation of glass, silicon, and metals.
- Eliminates the need for acid treatments (e.g., Nitric Acid, Sulfuric Acid, Hydrogen Fluoride).
- Works at room temperature, reducing energy use and contamination risks.
- Potential to enables the extraction and purification of high-grade silicon, a key material in semiconductors and microelectronics, supporting supply chains for chips, solar panels, and advanced technologies

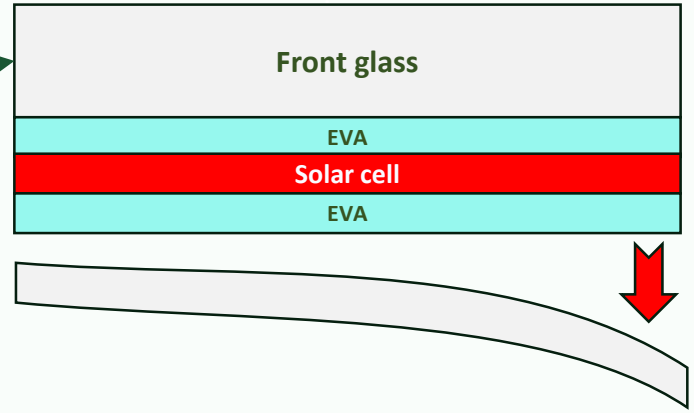
How Does it Work?

The Power of Microwave Delamination

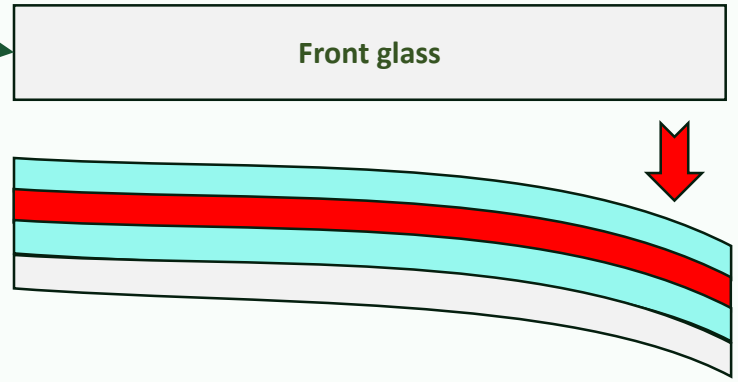


The targeted heating enables the easy separation of layers, allowing for efficient back sheet and front glass delamination

Backsheet delamination



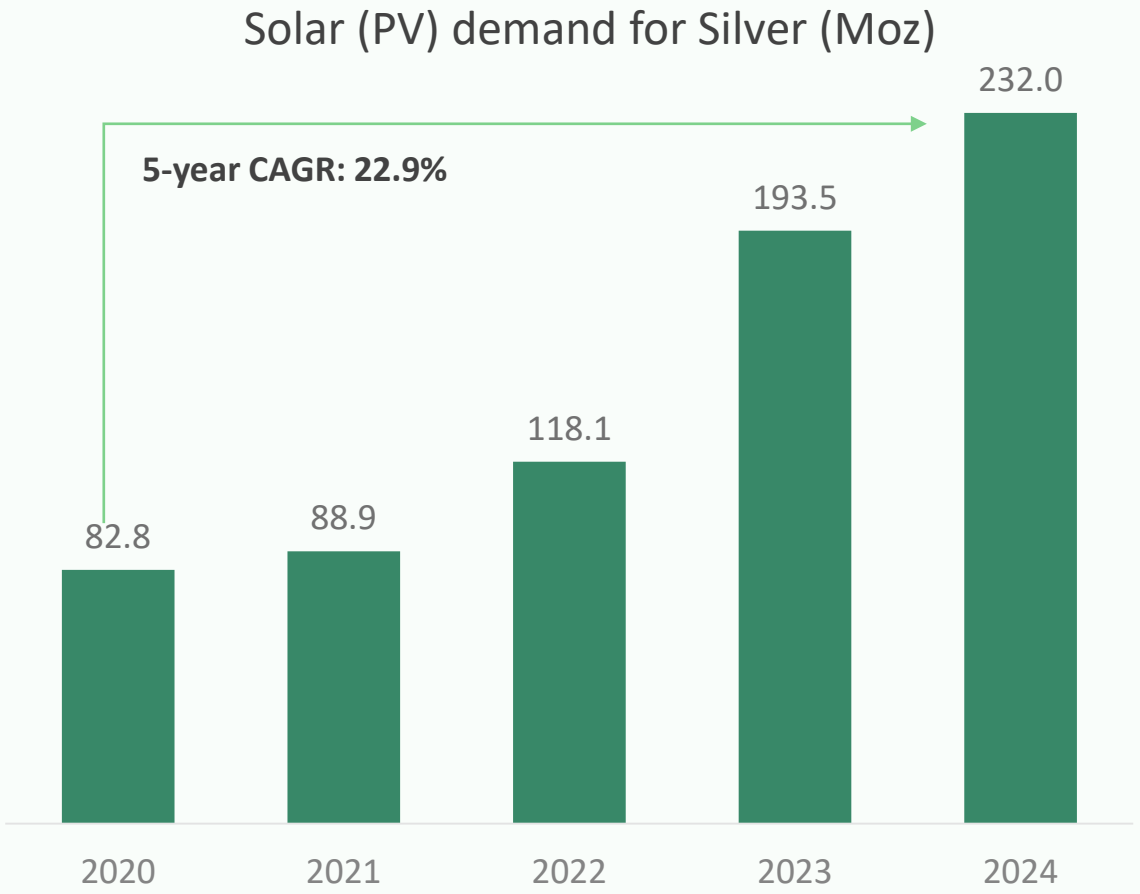
Front glass delamination



Delamination vs Crushing

Transforming Processes for a Better Tomorrow

Method	Crushing	Delamination
Process	Mechanical shredding of full panel	Layer-by-layer separation (thermal, chemical, or mechanical)
Material Integrity	High contamination, mixed fragments	Preserves materials in cleaner, separable form
Silvery Recovery	<5% (often lost in residue)	Up to 95–100% (near total recovery possible)
Silicon Recovery	Damaged or unusable	Intact and recoverable
Economic Value	~35% of panel value recovered	Potential for 3–4× higher value recovery compared to crushing[3]
Environmental Impact	Higher waste, more landfill	Enables circular economy, reduces environmental burden



[3] https://www.epj-pv.org/articles/epjpv/pdf/2024/01/pv230037.pdf (3.3)

Advancing Solar Panel Recycling with Microwave-Based Delamination

As the demand for semiconductors, renewable energy, and advanced electronics grows, the need for critical materials like silicon, silver, indium, and gallium is at an all-time high.

However, traditional solar panel recycling methods struggle to efficiently recover these valuable resources, leading to significant material loss and supply chain constraints.

Laminated Glass Structure – Solar panels are **encapsulated with EVA**, making separation of high-value materials difficult.

Silver-Silicon Bonding – Silver is directly bonded to **silicon wafers**, making it hard to extract without damaging the silicon.

Inefficient Traditional Methods – Conventional **crushing, acid leaching, and high-heat processing** often result in **low recovery rates, contamination, and high energy use**.

Inefficient Traditional Methods – Conventional **crushing, acid leaching, and high-heat processing** often result in **low recovery rates, contamination, and high energy use**.

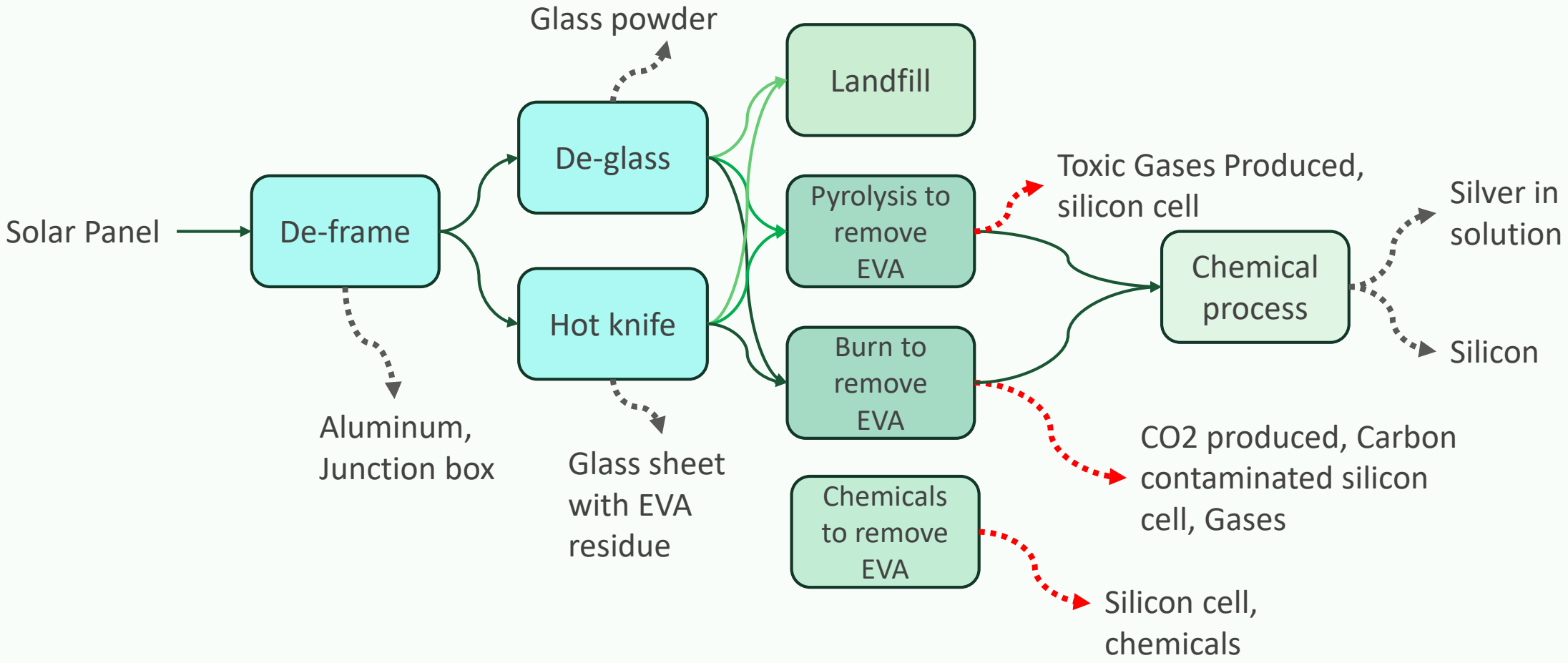
Advancing Solar Panel Recycling with Microwave-Based Delamination

Microwave Joule Technology based delamination softens the EVA encapsulant through targeted heating, enabling the clean separation of glass, silicon, and silver without the need for chemical treatments or mechanical force.

- Preserves **silicon wafers** for potential reuse in **semiconductor and solar applications**, reducing reliance on raw materials.
- Increases potential **silver recovery efficiency**, outperforming conventional **crushing and acid-leaching methods**.
- Ensures that **valuable materials remain intact**, improving recyclability and usability.
- Enhances the **financial viability of solar panel recycling** while supporting **critical mineral supply chains**.

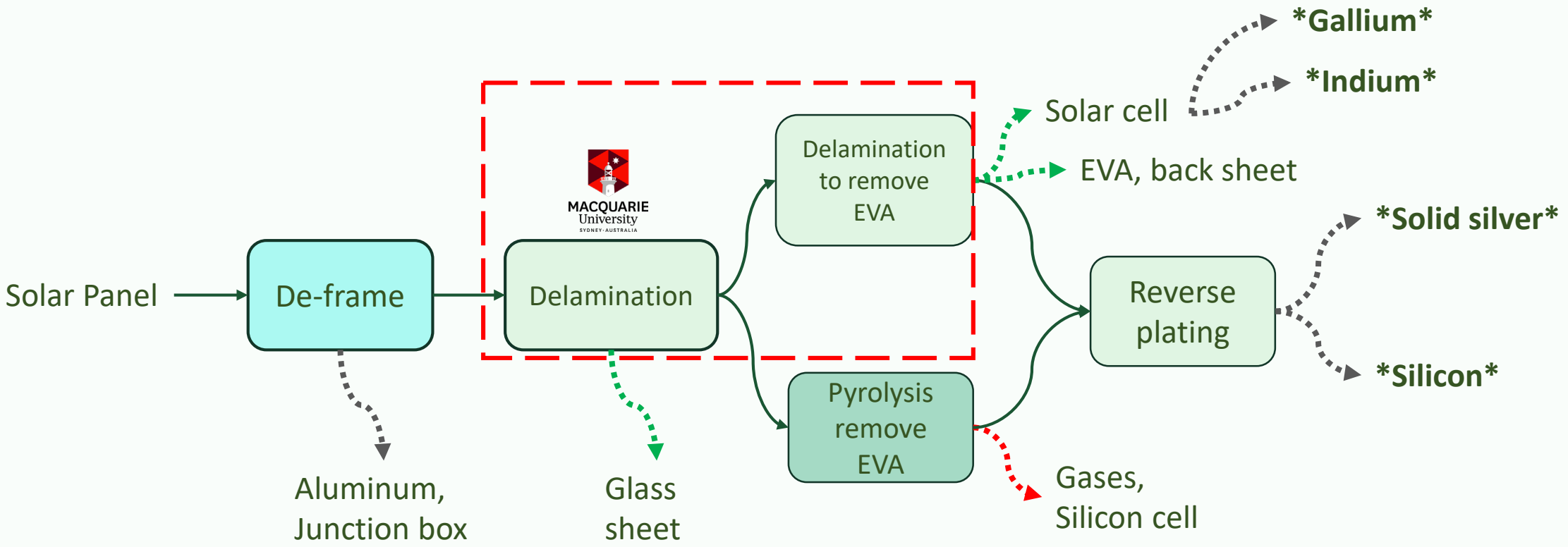
Solar Panel Recycling

Flow sheet to illustrate current process of Solar Panel Recycling



Solar Panel Recycling

The Proposed Model to recycle Solar Panels with MQ technology



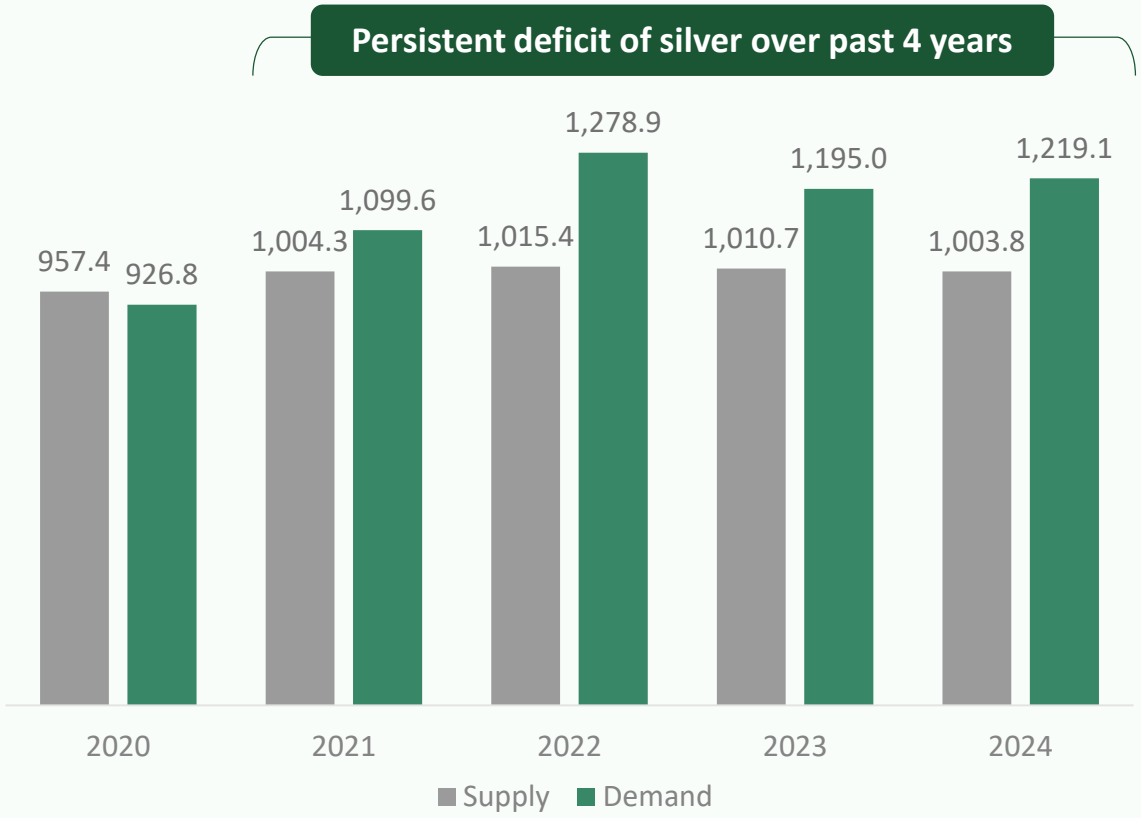
Future Opportunity

Silver Market Overview

Silver Market - Price and Volume

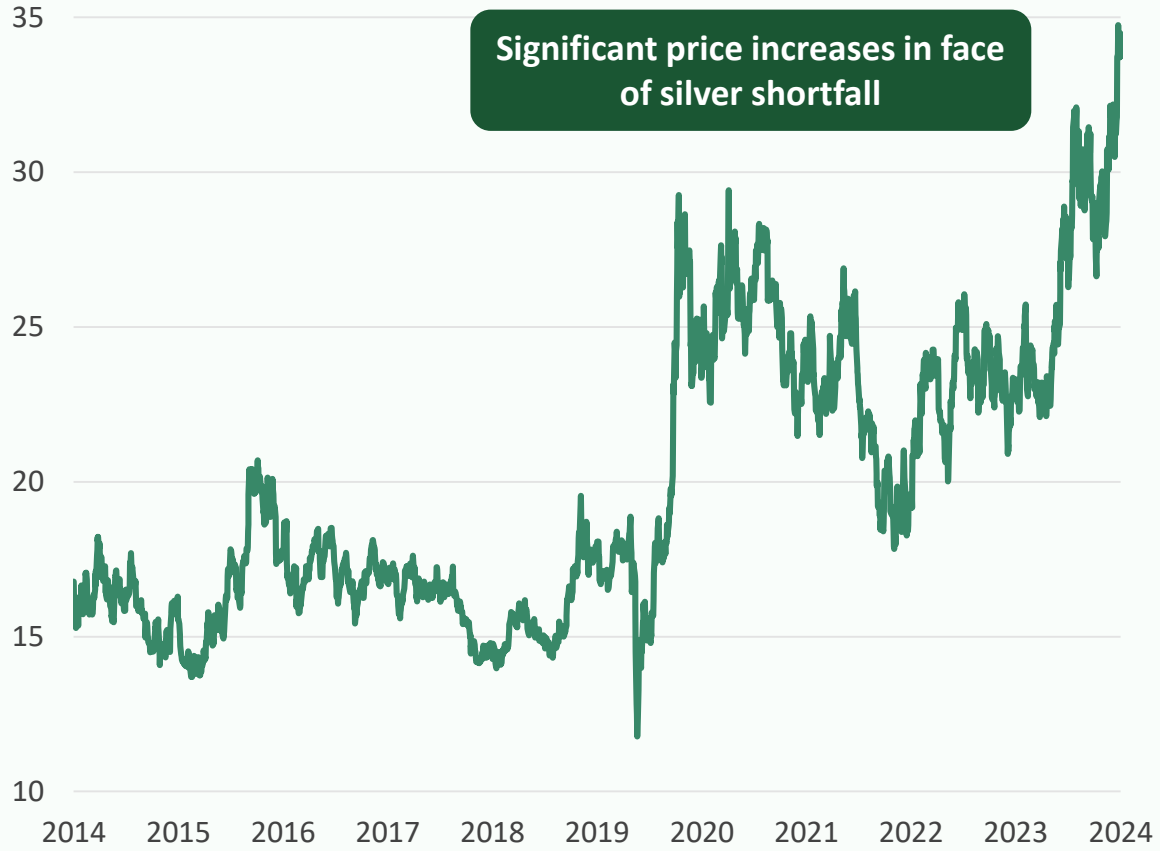
Deficit of silver supply versus demand driving silver price increases

Silver Supply and Demand (Moz)



Source: The Silver Institute, World Silver Survey 2024, April 2024

10-Year Silver Price Trend (USD/oz)



Source: MacroTrends, Silver Prices as at 1 November 2024

Industrial Uses of Silver

Industrial use is a major driver of growth in silver use globally

Major industrial uses for silver

Solar (PV) | Electric Vehicles (EV) | Batteries | Nuclear industry | Medical devices

Global industrial silver demand – 2023 (Moz)

Source: The Silver Institute, World Silver Survey 2024, April 2024

Industrial demand for Silver (Moz)

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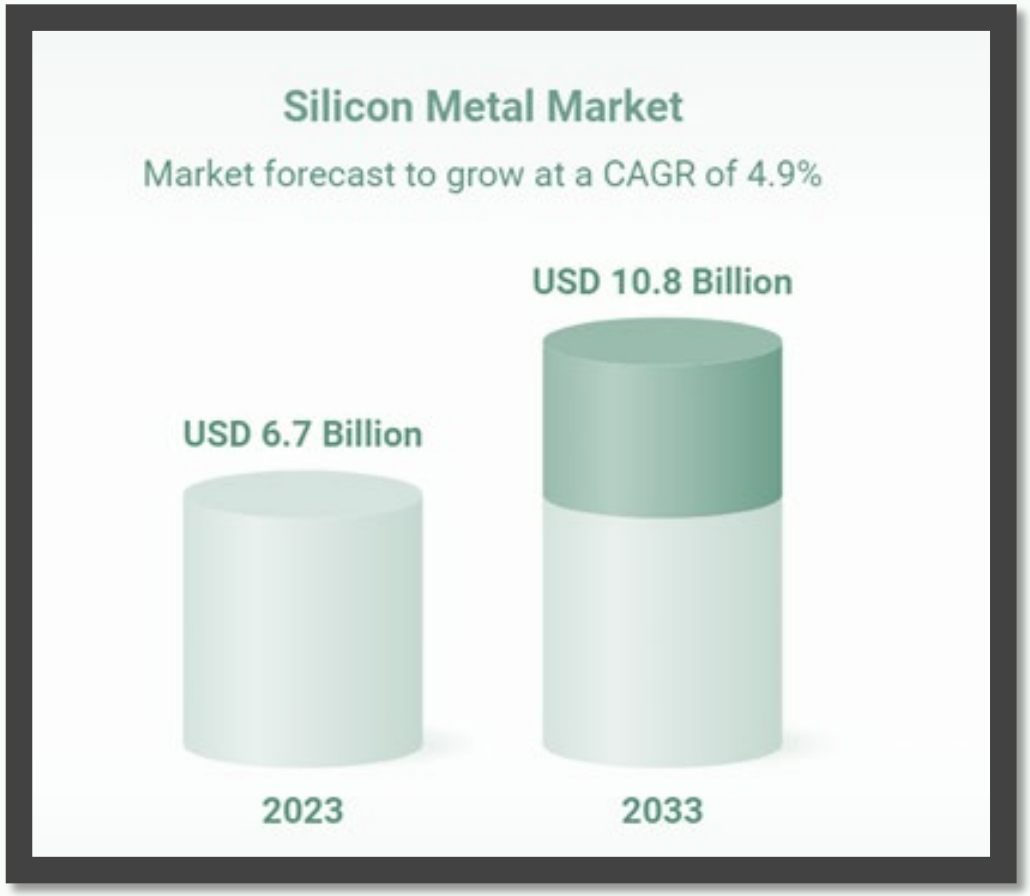
Silicon Market Overview

Silicon Market

Use Cases and Growth



Source: $10.75+ Billion Silicon Metal Global Market Opportunities

Major industrial uses for silicon

Solar (PV) | Electric Vehicles (EV) | Semiconductors | Construction | Medical devices

Crystalline silicon (c-Si) is the **primary material** in over **95% of solar panels**, enabling the **conversion of sunlight into electricity**.

Silicon carbide (SiC) power electronics improve **battery efficiency, charging speed, and range** in EVs

Silicon is the **foundation of computing**, used in **microchips, transistors, and AI processors** for **smartphones, 5G, and data centers**.

Silicone-based sealants, adhesives, and coatings improve **weather resistance, durability, and flexibility** in buildings

Medical-grade silicone is used in **implants, prosthetics, tubing, and surgical tools** due to its **biocompatibility and flexibility**

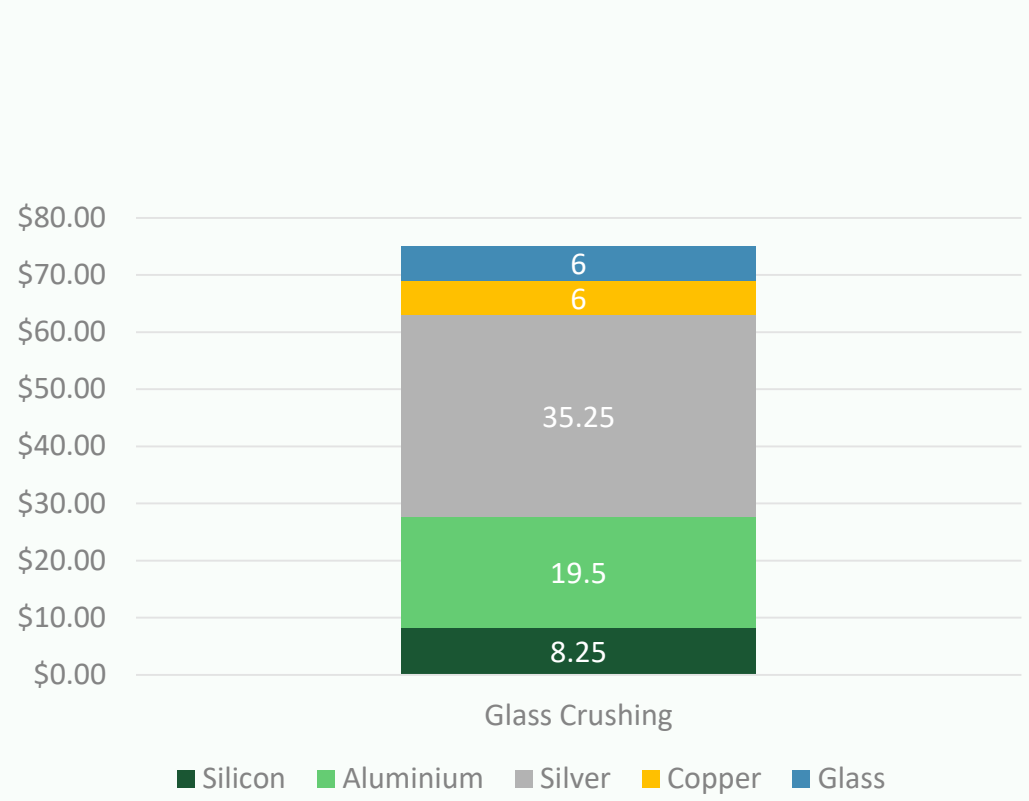
Glass Crushing VS Glass Recovery

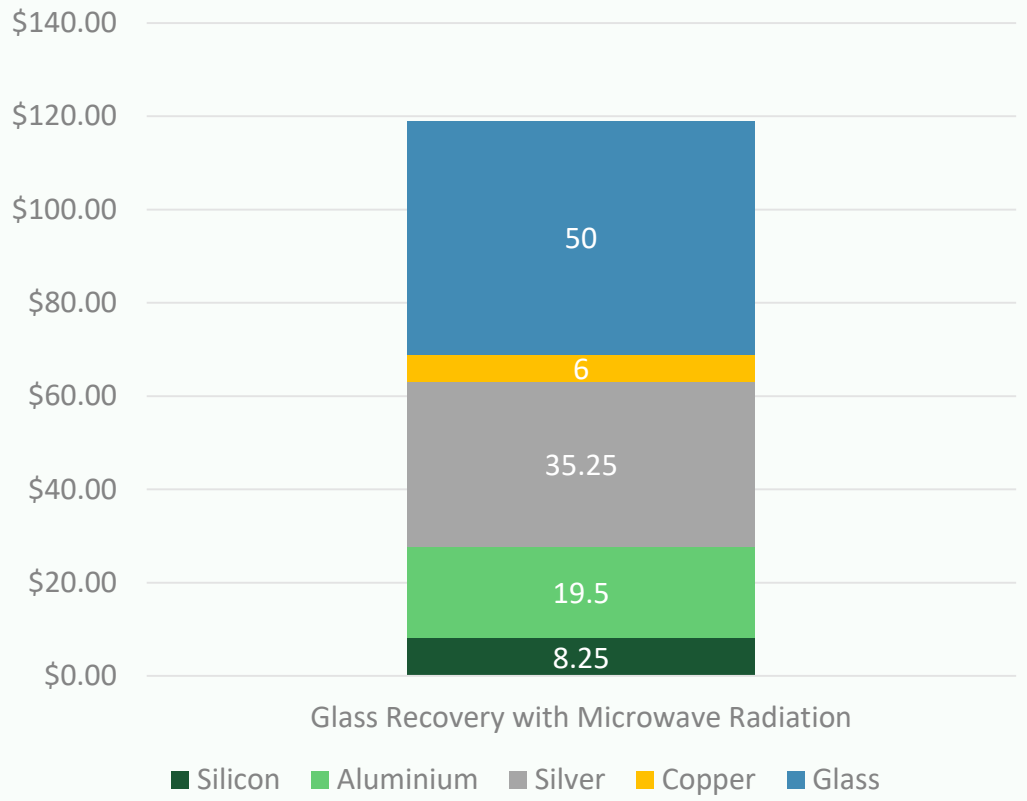
Delamination unlocks nearly **2x more value** per panel by preserving high-value materials

Total: $75

+58% increase in recovered value with delamination

Total: $119





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