

# ALUMINIUM (Al) IN SOLAR PANELS



## EXECUTIVE SUMMARY

Aluminium plays a critical and multifaceted role in the solar photovoltaic (PV) lifecycle, underpinning module durability, system performance, and long-term circularity opportunities. As one of the dominant metals in crystalline silicon PV systems, aluminium contributes several kilograms per panel and represents a significant share of material value within Australia's rapidly expanding solar fleet. With global PV installations now exceeding 2.2 TW and Australia surpassing 40 GW by the end of 2024, tens of millions of tonnes of aluminium are already embedded in renewable-energy infrastructure worldwide.

From a human-health perspective, aluminium in PV modules poses negligible risk. It is present as a stable, solid metal that does not provide a meaningful pathway for exposure during installation or use, and end-of-life (EoL) risks relate only to standard occupational hazards that can be effectively managed through existing safety protocols. The key environmental concerns sit upstream, where bauxite mining, alumina refining, and aluminium smelting carry substantial land-use, biodiversity and carbon-intensity impacts. These impacts highlight the importance of maximising aluminium recovery and closing material loops wherever possible.

Recycling offers a powerful mitigation pathway. Aluminium is one of the most straightforward and economically attractive materials to recover from EoL PV panels. Producing secondary aluminium requires only around 5% of the energy used for primary production and can avoid 8–12 tonnes of CO<sub>2</sub>-e per tonne of recycled metal. As Australia's PV systems begin to retire in large volumes from the

mid-2030s onward, the recovery of aluminium could offset a significant share of domestic demand and help underpin the development of emerging green aluminium hubs in different states and territories.

Looking forward, aluminium demand linked to solar PV is expected to rise substantially. Approximately 21 tonnes of aluminium are required per megawatt of installed PV capacity, creating strong alignment between solar deployment and the aluminium industry's decarbonisation trajectory. Globally, demand for aluminium may increase by up to 40% by 2050 – and potentially more than double under a 2°C climate scenario – with solar PV representing a major contributor. Australia, already a leading producer of bauxite and alumina, has a unique opportunity to connect end-of-life PV aluminium flows with national ambitions for low-carbon metals and manufacturing.

Together, these findings reinforce aluminium as a priority material for stewardship frameworks. Ensuring high recovery rates will deliver substantial emissions reductions, strengthen circular economy outcomes, and reduce reliance on emissions-intensive primary production. Targeted policy mechanisms – such as Extended Producer Responsibility schemes, minimum recycled-content requirements, design-for-disassembly standards, and mandated recovery rates – can accelerate investment in recycling capacity and align solar-sector material flows with Australia's broader climate and industry development goals. As a stable, high-value, and easily recyclable metal, aluminium presents one of the clearest and most immediately actionable pathways for advancing national solar stewardship.



## 1. ALUMINIUM IN SOLAR MODULES

Aluminium is one of the dominant metals used in crystalline silicon (c-Si) photovoltaic (PV) systems. Its combination of low weight, structural strength, corrosion resistance, and recyclability makes it ideal for the mechanical components that hold and protect PV modules throughout their 25–35 year operating life. Aluminium appears in several key PV system components:

- **Module frames (the silver rim around most panels):** Most PV modules installed globally today are framed modules, and the frame is the single largest application of aluminium in the PV module itself. The aluminium frame serves multiple critical functions: Structural integrity, load-bearing capacity, impact protection, ease of installation, electrical safety, and weather resistance. Because of these combined functions, aluminium frames are typically the second most expensive component of a PV module after the cells themselves, representing 10–15% of total module cost. Although frameless (glass–glass) modules are growing in niche segments (e.g., building-integrated PV), framed modules continue to dominate due to their lower breakage rates, simpler handling, and faster installation.
- **Mounting and racking systems:** Beyond the module frame, aluminium is also widely used in mounting systems, especially for rooftop rail systems (residential and commercial), clamps, brackets, and mid/end fasteners, ground-mount structures for small and medium-scale systems, and some tracker components (although steel dominates in utility-scale trackers). The choice of aluminium in these components is driven by several advantages. For residential and commercial rooftop installations, aluminium racking is often the preferred material, while large utility-scale solar farms more commonly rely on galvanised steel for cost efficiency.
- **Some inverter and junction-box housings and heat sinks:** Aluminium is a key material in various balance-of-system components for solar panels, although it's not the primary use. Its efficient heat dissipation contributes to better inverter reliability. Aluminium alloys are also used for internal fittings and enclosures, providing durability and heat tolerance. Furthermore, the high thermal conductivity and low density of aluminium make it suitable for certain connectors, earthing bars, and busbars, helping to maintain efficient cooling without significantly increasing the weight.

### 1.1 Aluminium Content per Solar Panel

Estimates vary by manufacturer, module size, and whether the panel is framed or frameless, but typical ranges are well characterised. An IEA PVPS life-cycle assessment reports that most silicon modules use an aluminium frame of about 2.1 kg per m<sup>2</sup>, while industry descriptions indicate frame masses up to ~3 kg per m<sup>2</sup>. A composition study of a “typical” crystalline silicon panel attributes roughly 12.7% of total module mass to aluminium which, for a 20 kg panel, corresponds to approximately 2.5 kg of aluminium. Taken together, these findings suggest that a practical and defensible estimate for aluminium content in a standard framed crystalline silicon panel is in the range of 2.5–4 kg per module, depending on module size and frame design.

Frameless or glass-glass modules can significantly reduce or eliminate frame aluminium, but globally the market is still dominated by framed modules.

### 1.2 Why Aluminium Is Used in PV Systems

Aluminium's widespread use in PV systems is largely driven by its intrinsic material properties. It is lightweight yet structurally strong, naturally corrosion-resistant, and easily formed into precise extrusions for frames and mounting systems. Aluminium is also highly thermally conductive, supporting heat dissipation in electrical components, and it retains its properties indefinitely when recycled. These characteristics make aluminium an ideal material for both module frames and rooftop mounting infrastructure, and they underpin its high economic value in end-of-life recovery.

## 2. HEALTH AND ENVIRONMENTAL CONSIDERATIONS

### 2.1 Human health

In PV applications, under normal use conditions, the health risks to households, installers, and the general public from aluminium in solar panels are considered negligible, especially when compared with the far greater background exposure to aluminium that occurs through everyday sources such as food, water, and consumer products.

At the end of life, the primary risks associated with aluminium in solar modules arise from general occupational hazards – such as sharp edges, dust generation, and interaction with mechanical equipment – rather than from aluminium toxicity

itself. These risks are effectively managed through established good practices, including controlled dismantling processes, dust suppression measures, appropriate machine guarding, and adherence to standard health and safety protocols used in the metal-recycling industry.

Overall, aluminium in solar modules poses negligible human health risk. It remains stable during use, with no meaningful exposure pathway, and end-of-life risks are routine occupational hazards that are easily managed with standard safety practices. As such, aluminium is not a health concern within PV systems.

## 2.2 Environmental risks

The key environmental risks associated with aluminium in solar modules arise upstream in the mining and refining stages and in the energy-intensive production of primary aluminium, rather than from the aluminium metal present within the panels themselves.

Bauxite mining – the first step in aluminium production – carries several important environmental risks that sit upstream of solar module manufacturing. Large-scale extraction can lead to land clearing, habitat and biodiversity loss, soil erosion, and disruption of surface and groundwater systems if not carefully managed. In regions such as Western Australia, assessments of mining activity near drinking-water catchments have highlighted the potential for sedimentation, pathogen influx, and hydrocarbon contamination when environmental controls fail. These impacts make the mining stage a critical component of aluminium’s overall lifecycle footprint, underscoring the need for strong regulatory oversight and rehabilitation practices.

Aluminium smelting also carries significant environmental implications due to its high energy demand. The aluminium sector emitted an estimated 1.12 billion tonnes of CO<sub>2</sub>-e in 2023, representing roughly 2% of global greenhouse gas emissions. Most emissions arise from the Hall-Héroult smelting process, which relies heavily on electricity and carbon-based anodes. In regions where smelters draw power from fossil-fuel sources, the resulting embodied emissions contribute substantially to the overall lifecycle footprint of PV modules, particularly through frames and mounting structures.

At the end of life, aluminium itself does not present major toxicity or leaching risks if landfilled, as the metal is largely inert. However, environmental losses

occur when frames are not recovered for recycling. These losses reflect the missed opportunity to offset the impacts of primary aluminium production and the unnecessary pressure placed on landfill capacity through the disposal of bulky metal components.

## 3. RECYCLING PATHWAYS AND PROCESSES

Aluminium is one of the most straightforward, valuable, and economically compelling materials to recover from EoL PV modules. Its high recyclability, established global scrap markets, and relatively simple mechanical separation make it a cornerstone material for circularity within the solar sector. Unlike more complex components such as laminated glass–silicon stacks, aluminium frames can be removed rapidly and recycled using mature industrial processes.

### 3.1 General Properties of Aluminium Recycling

Aluminium is highly suited to circular material flows. Producing secondary (recycled) aluminium requires only around 5% of the energy needed to produce primary aluminium, resulting in substantial greenhouse gas savings and significantly lower overall environmental impacts. Because aluminium retains its properties indefinitely through repeated recycling cycles, the quality of secondary aluminium is sufficiently high for nearly all structural and industrial applications, including new solar frames, construction materials, and automotive parts. Global forecasts indicate that demand for aluminium scrap is expected to triple by 2050, reflecting both the rising adoption of aluminium in low-carbon technologies and the strategic importance of recycled material in reducing emissions and production costs.

Recycling aluminium not only reduces energy use to around 5% of that required for primary production, but also delivers substantial greenhouse gas savings – typically 8 to 12 tonnes of CO<sub>2</sub>-e avoided for every tonne of aluminium recycled, depending on the carbon intensity of the displaced primary production. When applied to Australia’s future end-of-life PV fleet, the cumulative impact becomes significant: recovering aluminium frames alone could prevent millions of tonnes of CO<sub>2</sub>-e over the coming decades. Quantifying these avoided emissions reinforces the role of aluminium recovery as a high-impact stewardship strategy aligned with national decarbonisation goals.

## 3.2 PV-Specific Recycling Steps

Recycling processes for crystalline silicon PV modules follow several well-defined stages, with aluminium recovery playing an important early role.

- **Collection and pre-treatment:** EoL panels are first collected from residential rooftops, commercial buildings, and utility-scale solar farms and transported to dedicated recycling facilities. Pre-treatment often begins with the removal of external components, and in nearly all commercial recycling systems, the aluminium frame is the first part to be detached. This step is typically performed manually or with simple mechanical tools because the frame is bolted, clamped, or clipped onto the glass laminate, allowing for fast and low-cost separation.
- **Separation and sorting:** Once removed, aluminium frames are sorted away from glass, plastics, and the laminated cell stack. Because aluminium is both high-value and highly separable, recovery rates are extremely high, and the material is routinely channelled into established metal scrap streams. This contrasts with the more technically complex recovery of glass, silver, copper, and silicon, making aluminium a disproportionately important contributor to the economic viability of PV recycling.
- **Downstream metal recycling:** Separated frames are then processed in conventional aluminium-recycling systems. They are typically shredded, cleaned, and melted in secondary smelters to produce ingots or billets. These recycled products re-enter manufacturing supply chains and can be used in a wide range of applications, including new PV frames, architectural components, transport equipment, and consumer goods.
- **Integrated PV recycling plants:** Advanced, fully integrated PV recycling facilities are capable of recovering up to around 95% of the total material in a module, with glass, aluminium, and silicon contributing the majority of the recovered value. Research also shows that aluminium frames may undergo combined mechanical and thermal treatments as part of broader metallurgical processes designed to maximise yield and improve downstream separation of other materials in the module.

Overall, aluminium remains the most reliably and efficiently recovered material in PV recycling today, both technically and economically. Its ease of separation and strong scrap value help anchor the business case for PV recycling infrastructure and

make it a foundational component of any effective solar stewardship and circular-economy system.

## 4. ALUMINIUM DEMAND LINKED TO SOLAR PV

### 4.1 PV as a consumer of aluminium

Solar PV is now one of the world's most important emerging sources of demand for aluminium. Studies by European Aluminium and SolarPower Europe estimate that approximately 21 tonnes of aluminium are required per megawatt (MW) of installed PV capacity, largely due to the widespread use of aluminium in module frames, rooftop racking systems, and portions of utility-scale mounting infrastructure. This figure captures both the physical intensity of aluminium use and the scale of global solar deployment, making aluminium a strategic material for the energy transition.

On a global scale, cumulative installed PV capacity reached around 2,200–2,250 gigawatts ( $\approx 2.25$  TW) by the end of 2024. Applying the benchmark of 21 t/MW implies that the world's operational solar fleet now contains approximately 47 million tonnes of aluminium, primarily in frames and mounting systems. This value is an order-of-magnitude estimate, as aluminium intensity varies by system design – frameless modules and steel-dominant ground-mount structures reduce aluminium use, while larger framed modules or mechanically complex mounting systems increase it.

In Australia, cumulative installed PV capacity reached around 40 GW by the end of 2024. Using the same 21 t/MW indicator, Australia's operational PV systems embody roughly 0.84 million tonnes of aluminium. As with global estimates, this figure depends on local installation practices, the prevalence of framed modules, and whether rooftops or ground-mounted systems dominate.

Supporting this demand, the global aluminium solar-frame market was valued at approximately USD 15 billion in 2024 and is expected to almost double by the early 2030s. This growth reflects the increasing scale of PV deployment, the shift toward larger module formats requiring more robust frames, and the broader trend of aluminium being preferred over steel in rooftop and commercial mounting structures due to its light weight, corrosion resistance and ease of installation.

## 4.2 Solar as an enabler for aluminium

The aluminium–solar relationship is bidirectional. Aluminium is not only a critical input into solar deployment; solar energy is rapidly becoming a critical enabler of green, low-carbon aluminium production.

Aluminium smelters are among the largest single electricity consumers in national grids. In Australia, they account for roughly 10% of average National Electricity Market (NEM) demand, and more than 25% during minimum load periods, making them one of the most influential industrial loads in grid stability and decarbonisation planning. Because the Hall-Héroult process is electricity-intensive, access to low-cost, low-carbon energy is essential for competitiveness and emissions reduction.

Globally, smelters are increasingly looking to solar, wind, and firmed renewable energy to decarbonise operations. Integrating renewable energy into smelting processes is central to emerging “green aluminium” strategies, supported by both industry initiatives and government policy. In Australia, the federal government has committed approximately AUD 2 billion in production credits to support green metals, including aluminium, encouraging smelters to transition from fossil-based power to renewable electricity.

This creates a mutually reinforcing dynamic where aluminium enables solar through frames, racking, and structural systems, and solar enables aluminium by providing the clean electricity required to reduce the carbon footprint of primary aluminium production.

## 4.3 Australian Aluminium Industry Context

Australia plays a major global role in the aluminium supply chain as one of the world’s leading producers of bauxite and alumina, yet its domestic aluminium smelting capacity has been declining for more than a decade due to high electricity costs and increasing international competition. This dynamic is now shifting as national and state-level policies emphasise the creation of “green aluminium” hubs, particularly in Queensland, Tasmania and New South Wales (Tomago), where access to firmed renewable energy can support low-carbon smelting. These developments strengthen the strategic case for aligning PV-related aluminium demand with domestic decarbonisation initiatives. As Australia’s PV fleet grows and future end-of-life flows of aluminium increase, the sector has an opportunity to contribute directly to these emerging green-metal pathways,

creating a more circular, resilient and locally anchored aluminium industry.

## 4.4 Long-Term Demand Outlook

Looking ahead, the aluminium sector is expected to undergo substantial expansion driven by the clean energy transition. Global aluminium demand is forecast to rise by around 40% by 2050, with solar PV, electric vehicles, and grid infrastructure being major contributors. Under a 2°C climate scenario, analyses by the World Bank and industry groups suggest that total aluminium demand could more than double, with solar PV alone accounting for a significant share of incremental need due to its rapid global scale-up and large per-MW metal intensity.

As today’s installed PV systems begin reaching their end of life from the 2030s onwards, aluminium will also emerge as a major secondary resource stream and its recovery will play a central role in establishing circular-material flows within the solar industry. High-quality scrap generated from decommissioned PV systems will help meet rising demand while reducing dependence on energy-intensive primary production.

As Australia’s installed PV capacity continues to grow, the volume of aluminium returning to the economy at end of life will expand significantly from the mid-2030s through to the 2050s, reflecting the retirement of the large installation waves from the past decade. Aluminium makes up several kilograms per module, meaning that even conservative forecasts indicate that Australia could recover hundreds of thousands of tonnes of secondary aluminium over this period. These future flows have the potential to offset a meaningful share of domestic demand for primary aluminium, particularly as smelters transition toward low-carbon production. Incorporating end-of-life aluminium forecasts into stewardship planning therefore strengthens both national resource security and Australia’s broader strategy to develop a competitive green-metals sector.

## 5. KEY IMPLICATIONS FOR STEWARDSHIP AND POLICY

Taken together, the analysis highlights the material, environmental, and strategic importance of aluminium in the solar PV lifecycle. Each framed module contains several kilograms of aluminium, and when scaled across the global installed PV fleet, this represents tens of millions of tonnes of metal already embedded in renewable energy infrastructure. This scale

underscores aluminium's significance not only as a core input to solar deployment but also as a future secondary resource stream with considerable circular-economy potential.

From a health and safety perspective, aluminium presents minimal direct risk during panel use or handling. The primary environmental burdens instead arise upstream, where bauxite mining and aluminium smelting carry substantial land-use, biodiversity, and carbon-intensity impacts. These systemic pressures make the recovery of aluminium at end of life particularly valuable, as recycling drastically reduces energy consumption and greenhouse gas emissions relative to primary production.

Importantly, aluminium represents a high-value, low-friction recycling opportunity within PV modules. Frames are simple to detach, widely accepted by existing metal recyclers, and economically attractive due to their strong scrap value and the well-established market for secondary aluminium. This simplicity positions aluminium as one of the first materials that can be effectively “closed-looped” at scale, particularly in Australia, where a rapidly expanding solar fleet means large volumes of modules will reach end of life from the 2030s onward.

For policymakers and stewardship designers, aluminium offers a clear strategic entry point for building circularity into the solar industry. Ensuring high-recovery rates will not only reduce the embodied emissions of future PV systems but will also contribute to developing a domestic supply of recycled aluminium to support Australia's emerging clean-manufacturing and green-metals ambitions.

A range of policy levers could strengthen this transition. Extended Producer Responsibility (EPR) schemes, minimum recycled-content requirements, or mandated recovery targets for aluminium in PV systems would incentivise investment in dedicated recycling capacity and encourage manufacturers to design for disassembly. Such measures would also support better alignment between the solar sector and national emissions-reduction strategies, particularly given the momentum behind green aluminium and the increasing role of renewable energy in industrial decarbonisation.

Overall, aluminium stands out as a priority material for stewardship frameworks—large in volume, simple to recover, and capable of delivering substantial environmental benefits when recycled effectively.

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