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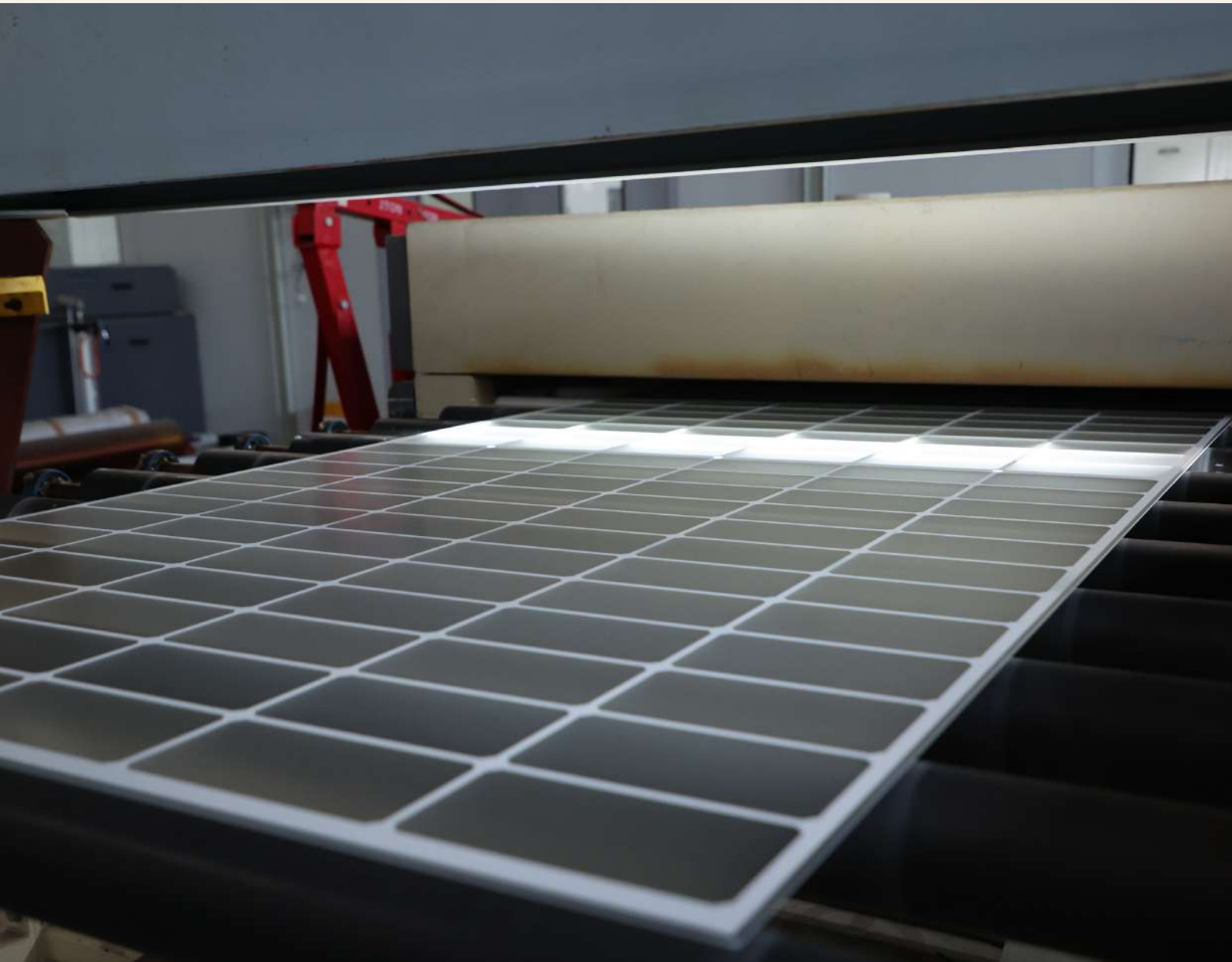
Report | November 2026

Shaping India's Next Phase of Solar Manufacturing

From Capacity Gap to Global Opportunity in India's Solar Bill of Materials Industry

Authors

Ajinkya Kale
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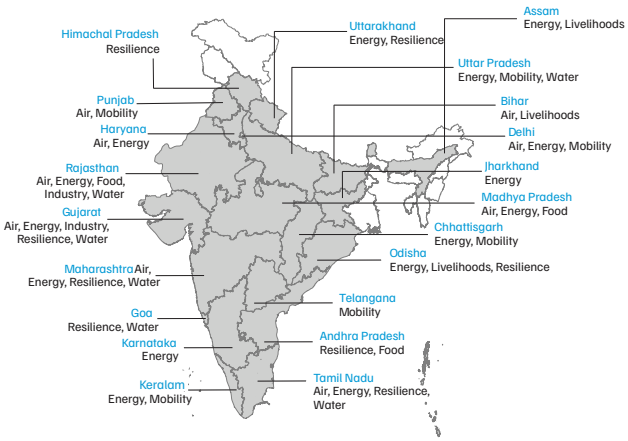




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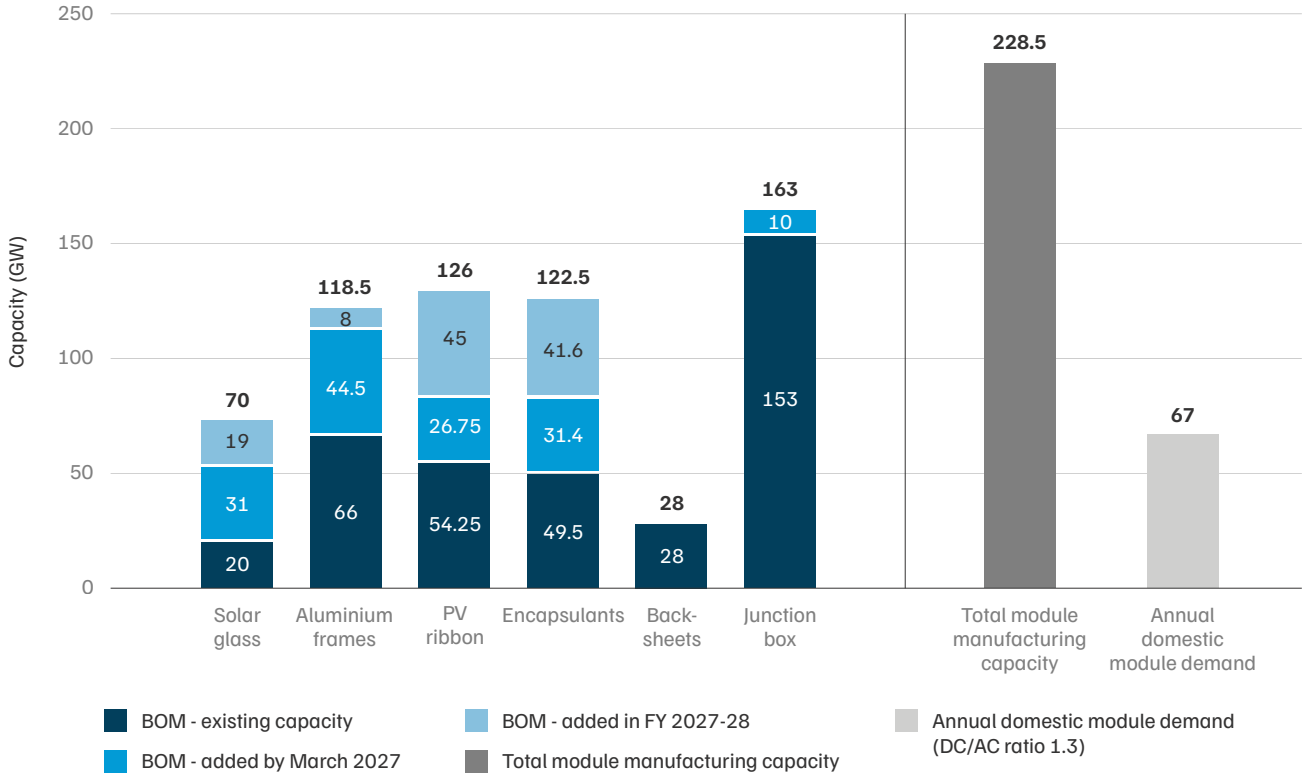
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Executive summary

As of September 2026, India's solar module manufacturing capacity under ALMM List-I stands at 228.5 GW (MNRE 2026a). While the bill of materials (BOM) used in every module – solar glass, aluminium frames, photovoltaic (PV) ribbons, encapsulants, backsheets, and junction boxes have significantly lower domestic manufacturing capacities and remain heavily import-dependent[1]. Additionally, the domestic BOM manufacturing ecosystem faces several critical challenges that require urgent attention – ranging from manufacturing complexities and inconsistent quality control practices to regulatory hurdles. This study identifies pathways to overcome these challenges, supporting the creation of a resilient, self-reliant solar BOM industry and establishing India as a trusted global solar manufacturing hub.

Based on data from the Solar Ancillary Manufacturers' Association (SAMA), as of September 2026, domestic BOM manufacturing capacities per annum ranged from **20 GW for solar glass**, the lowest among the six components, to **153 GW for junction boxes**, the highest. Manufacturing capacities for the other components were **66 GW for aluminium frames, 54.25 GW for PV ribbons, 49.5 GW for encapsulants, and 28 GW for backsheets** (Figure ES1). By March 2028, planned expansions by existing and new players are estimated to increase cumulative manufacturing capacities to 70 GW for solar glass, 118.5 GW for aluminium frames, 126 GW for PV ribbons, 122.5 GW for encapsulants, and 163 GW for junction boxes.[2] These planned expansions reflect growing investor confidence across the BOM value chain.

Figure ES1. By March 2027, existing and upcoming BOM manufacturing capacities would be sufficient to meet India's annual module demand, except for solar glass



Source: Authors' analysis based on September 2026 data from SAMA, MNRE 2026a, and NITI Aayog 2023.

1. Other BOM components, such as silver paste, adhesives, potting compounds, mounting hardware, and interconnect tapes, are not included in the current scope of work.
2. No planned expansion of backsheet capacities due to the rise in adoption of glass–glass modules in India. For junction boxes, the cumulative capacity is expected to come online until March 2027.

However, between FY2021 and FY2026, imports of these BOM components surged. **Imports of solar glass recorded a compound annual growth rate (CAGR) of 63 per cent,[3] aluminium frames 88 per cent,[4] PV ribbons 51 per cent,[5] encapsulants 68 per cent,[6] backsheets 15 per cent,[7] and junction boxes 92 per cent[8]** (MoCI 2026a). India's growing reliance on imported BOM components is concentrated among a small number of supplier countries. For instance, in FY2026, China accounted for 66 per cent of India's total glass imports and 70 per cent of its total aluminium frame imports, while Malaysia accounted for 22 per cent of its total solar glass imports. Vietnam and Thailand accounted for 34 and 31 per cent, respectively, of total encapsulant imports[9]. This concentration leaves India's module manufacturing base exposed to price volatility, supply chain disruptions, and shifts in foreign trade policies.

Expanding domestic BOM manufacturing will **strengthen supply chain resilience** while presenting an opportunity for **India to emerge as an alternative source for international markets** seeking to diversify their supply chains. Beyond supply chain security, stronger domestic BOM manufacturing capabilities can **provide greater control over product development**, including access to innovation in product design, material use, and manufacturing processes. It will also **unlock jobs and investments** and contribute to progress towards *Atmanirbhar Bharat*. Further, global policy changes and trade measures necessitate enhancing domestic BOM capacity. For example, China's value-added tax (VAT) rebate cuts effective April 2026 (MOF China 2026), and India's anti-dumping duties, have together raised the landed costs for imports. While this creates an opportunity for domestic BOM manufacturing to substitute imports, insufficient local production volume – particularly during the build-out phase – risks disrupting domestic solar module manufacturing unless planned expansions are realised on schedule.

Moreover, translating nameplate capacity into reliable and commercially competitive output requires addressing fundamental technological, manufacturing, quality assurance, supply chain, regulatory, and financial challenges. **This study identifies these barriers by mapping gaps in manufacturing processes and raw material requirements across BOM components, analysing trade barriers and their impacts, and assessing performance differences between the product models and variants offered by international and domestic BOM manufacturers**. Based on this analysis, the study provides recommendations for domestic manufacturers and policymakers to establish a reliable, cost-competitive, and technologically advanced BOM manufacturing hub capable of closing India's capacity gap and positioning the country as a global leader in the sector.

Key findings

- **As of September 2026, India's solar BOM manufacturing market is valued at approximately USD 3.61 billion,[10] and it is estimated to reach approximately USD 7.78 billion by March 2028**, driven by planned capacity expansions by existing players and new entrants.

- **By March 2027, planned capacity expansions for aluminium frames, PV ribbons, and encapsulants would be sufficient to meet annual module demand of around 67 GW** (Figure ES1).[11] Domestic solar glass manufacturing capacity would be sufficient to meet this demand by March 2028. Junction boxes are the only BOM segment with sufficient capacity to meet this annual demand at present.

3. Solar glass imports grew from USD 128.56 million to USD 1,480.07 million in the period FY2021–FY2026.
4. Aluminium frame imports increased from USD 24.77 million to USD 586.65 million in the period FY2021–FY2026.
5. PV ribbon imports grew from USD 15.66 million to USD 122.83 million in the period FY2021–FY2026.
6. EVA encapsulant imports grew from USD 40.82 million to USD 551.1 million in the period FY2021–FY2026.
7. Backsheet imports increased from USD 74 million to USD 149.64 million in the period FY2021–FY2026.
8. Junction box imports grew from USD 5.57 million to USD 144.93 million in the period FY2021–FY2026.
9. All import shares are by value. Calculations are done based on the trade statistics from MoCI (2026a).
10. The market for solar backsheets has been excluded from the overall market size estimate due to the significant decline in demand resulting from the increased adoption of glass–glass modules in the country.
11. We assume the annual module demand to be synonymous with the actual annual solar deployment in the country. India installed 44.61 GW of solar in FY2026, bringing the cumulative capacity to 150.26 GW. As per NITI Aayog's *India Energy Security Scenarios* (IESS) 2047 V3.0, cumulative solar capacity installations will reach 1,233.59 GW by 2047, under its net-zero scenario (NITI Aayog 2023). The required annual installation capacity to achieve this is 51.58 GW from FY2027 to FY2047. Assuming an direct current to alternating current (DC:AC) ratio of 1.3, this would require ~67 GW of DC annual solar module installation.

- **India has multiple manufacturers across all six BOM components**, indicating commercial-scale production capabilities, steady market demand, a competitive domestic manufacturing landscape, and significant opportunities for innovation. Each BOM component has at least **six domestic manufacturers**, and the largest manufacturers across components have production capacities of at least ***6* GW per annum**. However, significant technological, supply chain, and regulatory gaps remain across the ecosystem.

- **Domestic BOM manufacturers have introduced a range of component variants, but there remains an opportunity to expand their portfolios to include product innovations for new-age module technologies** offered by global counterparts. These include reflective PV ribbons for higher optical gains, low-temperature PV ribbons for advanced module technologies such as heterojunction (HJT), and composite frames for reduced weight and enhanced corrosion resistance. Failure to adopt emerging technologies could result in domestic manufacturers losing market share and, over time, their product offerings becoming obsolete.

- **Domestic manufacturers are dependent on raw material imports to produce BOM components**, including sodium antimonate, soda ash, limestone, and dolomite for solar glass; polymer resins for encapsulants and backsheets; and bypass diodes and copper wires for junction boxes. Market volatility can cause **fluctuations in raw material prices**, impacting domestic manufacturers' profit margins and undermining their cost-competitiveness. Import dependence also increases **vulnerability to global supply chain disruptions**, which can constrain domestic manufacturing.

- **All six BOM components lack dedicated Harmonised System (HS) classifications and are imported under multiple HS codes** (MoCI 2019, 2022, 2024a, 2025a; MoF 2026a). This lack of standardisation prevents accurate estimation of import volumes and values, undermining the reliability of trade statistics. It also weakens customs monitoring and makes it challenging for authorities to effectively implement trade remedies, such as anti-dumping and countervailing duties, which are typically linked to specific HS codes. Misclassification puts compliant domestic manufacturers at a competitive disadvantage, as it enables duty evasion and regulatory arbitrage by importers, allowing them to avoid applicable tariffs and quality control measures.

- **Domestic BOM manufacturers follow a selection of testing protocols and standards**. However, the **absence of standardised testing criteria can lead to variations in the quality of locally produced BOM components**, compromising their reliability and performance. Global manufacturers also undertake advanced tests to deliver top-quality products to their customers. These quality-control inconsistencies can undermine buyer confidence in domestically produced BOM components.

Key recommendations

To meet the country's growing demand for high-quality, cost-competitive products while maintaining global competitiveness, the study provides recommendations for India's BOM manufacturers and policymakers, as summarised in Table ES1 and a detailed breakdown thereafter.

Table ES1. Strategic measures to be taken by bill-of-materials manufacturers and policymakers to enable a resilient and globally competitive solar industry

Cross-component recommendations	
• **On supply-side measures** » Domestic BOM manufacturers should add newer product variants to their product portfolio to meet the performance requirements of advanced module technologies. » BOM manufacturers should create a domestic ecosystem that can serve as an additional source of raw materials. » The Central Board of Indirect Taxes and Customs (CBIC), in coordination with the Directorate General of Foreign Trade (DGFT) and the Directorate General of Trade Remedies (DGTR), should introduce dedicated HS codes for all product variants of individual BOM components. » The Ministry of New and Renewable Energy (MNRE), the Bureau of Indian Standards (BIS), and BOM manufacturers should collaborate to develop and set uniform testing standards and guidelines for all BOM components.	
• **On demand-side measures** » The MNRE should introduce an Approved List of Models and Manufacturers (ALMM) for all BOM components and extend the *Domestic Content Requirement* (DCR) mandate to all BOM components to anchor domestic demand.	
Component specific recommendations	
Solar glass	• Manufacturers should improve solar glass quality by adopting robust manufacturing practices and strengthening testing protocols, especially for thinner glass sheets used in bifacial modules, to deliver solar glass that meets international standards. • As solar glass production is highly energy-intensive, manufacturers should aim to procure renewable energy for their operations to reduce their operating costs. They should also establish backup arrangements for natural gas supplies via setting up on-site storage units or diversifying their gas supply-chain through local sourcing to avoid purchasing gas at inflated prices during periods of global supply disruptions.
Aluminium frame	• Manufacturers should expand their product portfolios to include products made with advanced materials, such as frames made of composite materials and galvanised steel, to maintain market relevance. • Manufacturers should secure their raw material supply through long-term contracts with domestic suppliers, such as National Aluminium Company Ltd (NALCO) and Bharat Aluminium Company Ltd (BALCO), for financial de-risking. However, domestic raw materials exceed global price benchmarks. Easing duties on frame-grade aluminium inputs is urgently needed to bridge this cost gap.
PV ribbon	• Manufacturers should add newer PV ribbon technologies, such as reflective ribbons, multi-busbar (MBB) and zero-busbar (0BB) ribbons (used for increasing module efficiencies), and low-temperature ribbons (used in HJT and perovskite production) to remain aligned with evolving market trends.

Encapsulant	• Manufacturers should strengthen collaboration with domestic resin manufacturers that have complementary capabilities, including petrochemical companies such as Gas Authority of India Limited (GAIL) and Indian Oil Corporation Ltd (IOCL), to enhance supply chain resilience. They should jointly design pilots for local ethylene-vinyl acetate (EVA) resin manufacturing, supported by the Ministry of New and Renewable Energy (MNRE) and Ministry of Petroleum and Natural Gas (MoPNG). • Manufacturers, the MNRE, and the Bureau of Indian Standards (BIS) should standardise quality control across domestic encapsulant manufacturers to ensure consistent product performance and reliability, increasing buyer confidence.
Backsheet	• While demand for backsheets has declined, existing market players should focus on transparent backsheet production to retain demand from bifacial module manufacturers. Their lighter weight compared with solar glass makes modules using them particularly suitable for rooftop applications, where structural load capacity may be a constraint. • Manufacturers should collaborate with local resin suppliers to build a resilient raw material supply chain, reducing the impacts of global supply chain disruption.
Junction box	• Junction box manufacturers, in collaboration with module manufacturers, should explore the development of adaptable junction box designs for improved reliability and performance. • The Ministry of Electronics and Information Technology (MeitY) and the MNRE should collaborate to strengthen domestic manufacturing of bypass diodes by including them under the *Electronics Component Manufacturing Scheme* (ECMS), released in 2025, to secure the raw material supply chain.

Source: Authors' analysis.

- **Domestic BOM manufacturers should expand their product portfolios to include newer product variants and technologies that meet the performance requirements of emerging module technologies within the next two financial cycles – FY2028 and FY2029, addressing gaps in domestic product offerings.** For instance, PV ribbon manufacturers should offer reflective and multi-busbar (MBB) ribbons to module manufacturers seeking higher efficiencies through improved optical gains. Demand for such BOM variants is expected to increase as the market advances towards solar module technologies that are cheaper, lighter, more durable, and more efficient than earlier technologies. Expanding their portfolios will help BOM manufacturers remain competitive domestically while accessing global markets where these components are in demand.
- **Indian BOM manufacturers should develop a domestic ecosystem for raw materials**, reducing their exposure to market volatility and global supply chain disruptions. To achieve this, manufacturers should **collaborate with industries with complementary capabilities** to design and upgrade manufacturing processes capable of producing high-quality raw materials that meet their requirements. For instance, encapsulant manufacturers and established resin manufacturers, particularly in the oil and gas industry, should collaborate to indigenise the production of polymer resins such as ethylene-vinyl acetate (EVA) and polyolefin elastomer (POE). Domestically sourced raw materials must match the quality of imported alternatives and be supplied at prices that enable manufacturers to produce finished goods that are cost-competitive with imported BOM components.

- **The Central Board of Indirect Taxes and Customs (CBIC), in coordination with the Directorate General of Foreign Trade (DGFT) and the Directorate General of Trade Remedies (DGTR), should introduce dedicated HS codes for different variants[12] of BOM components before the Union Budget 2027–28**. Dedicated codes would enable more accurate tracking of import volumes and strengthen the implementation of trade remedies, such as anti-dumping and countervailing duties, helping ensure these trade barriers are properly enforced and achieve their intended policy objectives.

- **The Ministry of New and Renewable Energy (MNRE), the Bureau of Indian Standards (BIS), and BOM manufacturers should collaborate to develop uniform testing standards and guidelines for all BOM components at the earliest**. Uniform standards would ensure consistency in quality checks and improve buyer confidence. The standards should also align with international standards to support the quality and global acceptance of Indian products.

> Both supply-side and demand-side measures are required to build a resilient and globally competitive solar manufacturing hub.

- **The MNRE should introduce an Approved List of Models and Manufacturers (ALMM) for all BOM components to promote their uptake by domestic module manufacturers**. ALMM acts as a non-tariff barrier and promotes domestic manufacturing by heavily restricting imports. The list should be introduced by January 2028 and take effect from January 2029, providing BOM manufacturers sufficient time to establish their facilities and optimise manufacturing processes, thereby preventing supply-chain bottlenecks for module manufacturers. Moreover, **the MNRE should extend its *Domestic Content Requirement* (DCR) to include all BOM components**, creating an additional anchor for domestic demand. The DCR mandate should be made effective from January 2028, allowing module manufacturers to seamlessly transition to domestic BOM components. Introducing DCR will mandate local BOM usage across subsidy-linked rooftop and agricultural programs, and other Central Public Sector Undertakings (CPSUs) and government-tendered projects.

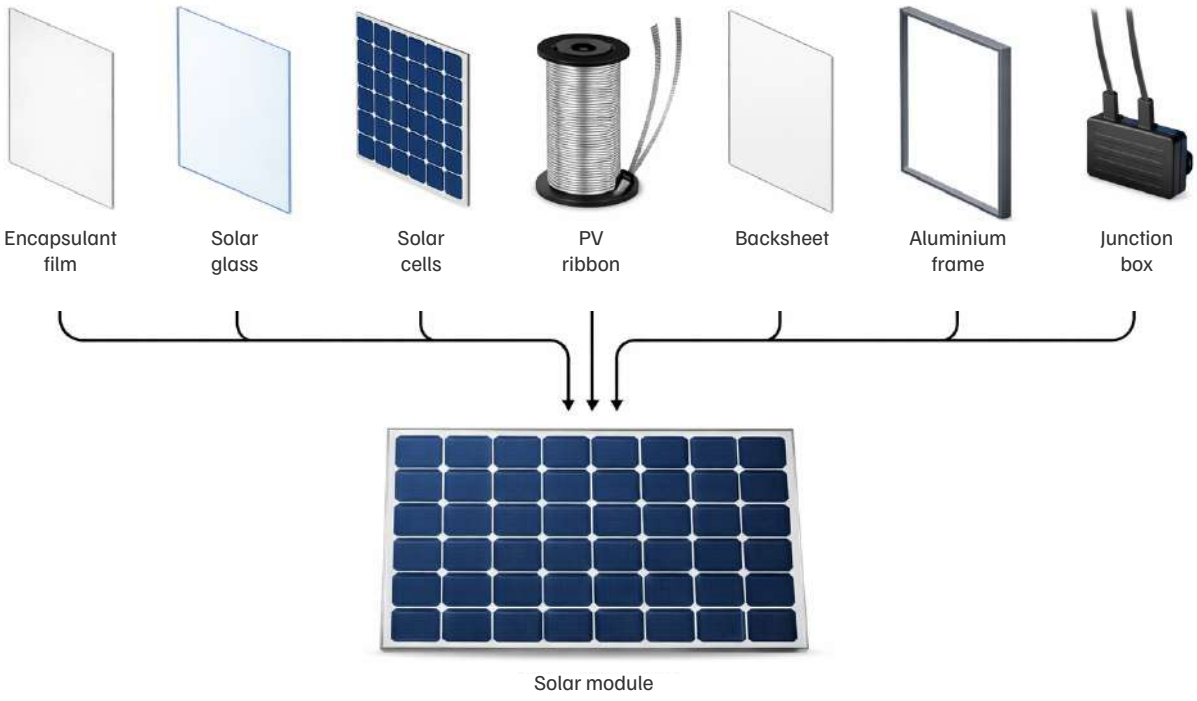
12. Variants differ in their material composition and end-use application.

1. Introduction

India's solar module and cell manufacturing capacities have reached 228.5 GW (MNRE 2026a) as of September 2026 and 37.8 GW (MNRE 2026b) as of October 2026, respectively, according to the Approved List of Models and Manufacturers (ALMM). Upstream manufacturing segments, such as ingot–wafer and polysilicon manufacturing, are expected to materialise as early as 2028. While polysilicon-to-module manufacturing constitutes the core of the solar manufacturing supply chain, ancillary components used in module production are equally critical to the growth of India's solar industry and manufacturing sector.

These ancillary components, collectively referred to as the bill of materials (BOM), include solar glass, aluminium frames, encapsulants, backsheets, junction boxes, and photovoltaic (PV) ribbons. Together with solar cells, these components make up a solar PV module, as illustrated in Figure 1.

Figure 1. A typical solar module consists of a cell array sandwiched between glass, encapsulant, and backsheet layers, encased within an aluminium frame



Source: Generated by the authors using artificial intelligence (AI).

Module manufacturers import most of these BOM components for three key reasons:

1. According to our stakeholder consultations across all BOM components, module manufacturers have greater confidence in the quality of imported components than in domestically manufactured components.

2. Imported components are, in most cases, cheaper than locally produced components.

3. Domestic BOM manufacturing capacity has not kept pace with module deployment, leading to a supply–demand mismatch.

This import dependence can have significant structural implications. First, it increases the vulnerability of the domestic solar module manufacturing industry to supply chain disruptions. For example, in October 2025, China announced an export ban on items related to lithium batteries and artificial graphite anode materials to safeguard its national security and interests (MOFCOM 2025), creating supply chain challenges for electric vehicle (EV) battery manufacturers. Similar disruptions could affect the solar PV supply chain given its dependence on imported BOM components. Second, import dependence could impede India's energy security goals by limiting the country's ability to build a self-reliant and resilient renewable energy ecosystem. Third, it could constrain the growth of the domestic BOM manufacturing sector, resulting in lost opportunities for jobs and investment and slowing progress towards *atmanirbharta*.

Beyond these challenges, there are also opportunities for domestic BOM manufacturing. In April 2026, China cancelled the value-added tax (VAT) rebate on photovoltaic products, raising export prices (MOF China 2026) and increasing the cost for module manufacturers. Combined with India's anti-dumping duties on BOM imports (MoCI 2019, 2022, 2023a, 2024a, 2025a), this is expected to significantly increase the landed cost of Chinese goods. India could capitalise on this opportunity for import substitution and increased market share by expanding domestic BOM manufacturing. Further, demand-side policies in key export markets are increasingly rewarding China plus one supply.

For example, the European Union's *Net-Zero Industry Act* (NZIA) requires resilience criteria in public procurement and renewable energy auctions - it gets triggered when a single third country supplies more than half of a net-zero technology or imports from a single third country have increased by at least 10 percentage points on average for two consecutive years to reach at least 40 per cent (European Parliament and Council of the EU 2024). India's installed manufacturing base provides a structural foundation for producing BOM at scale. As of September 2026, the domestic BOM market is valued at approximately USD 3.61 billion.[13]

However, scaling up existing capacities without addressing existing challenges could constrain the sector's growth. First, dumping of low-cost BOM components from China affect the revenues of domestic manufacturers. To safeguard domestic industry, the Ministry of Finance (MoF), on the recommendation of the Directorate General of Trade Remedies (DGTR), Ministry of Commerce and Industry, has imposed anti-dumping duties on solar glass, aluminium frames, and ethylene-vinyl acetate (EVA) encapsulants, which will remain valid until 2029 (MoCI 2025a). These components are imported under multiple HS codes which makes it difficult for the regulator to implement the anti-dumping duties and also risk duty evasion by importers. Second, variations in the quality checks conducted by domestic manufacturers can undermine buyer confidence. For example, domestic encapsulant manufacturers use different testing standards: some follow International Organization for Standardization (ISO) standards (RenewSys 2025a), while others follow American Society for Testing and Materials (ASTM) standards (Vishakha Renewables 2025a), resulting in variations in testing protocols and priority parameters. These differences can lead to inconsistent quality assurance practices across the industry. Third, with limited number of product offerings, domestic BOM manufacturers risk market obsolescence. Newer module technologies demand BOM components that improve their efficiency and durability such as reflective and low temperature ribbons, and frames made out of composite materials that have enhanced corrosion resistance properties. Manufacturers unable to make a shift to such variants and supply to the market will lose out to those who have included them in their product portfolio.

13. Calculations for the current market size of BOM are provided in Annexure 1. To view the annexures, please scan the QR code at the back of the report.

As India seeks to become a global solar manufacturing hub and diversify supply chains for international markets, addressing these challenges and strengthening the domestic BOM manufacturing ecosystem will be critical to supplying durable, high-quality, and cost-competitive products.

Objective

To support creating a resilient and self-reliant domestic solar BOM manufacturing industry, the study presents details on the industry's current status, the key challenges faced by BOM manufacturers, and measures needed to overcome these challenges. The study begins with examining the domestic market, before outlining the manufacturing process and raw materials required. This is followed by a trade data analysis on the import dependence and trade-related and non-trade barriers affecting domestic manufacturing. Building on this analysis, the study identifies the key challenges across the technological, manufacturing, quality assurance, supply chain, financial, and regulatory dimensions, and their impact on the competitiveness and growth of domestic BOM manufacturers. Finally, we propose a list of actionable recommendations for BOM manufacturers and policymakers to inform their decision-making and also support the development of a globally competitive BOM manufacturing industry producing high-quality and cost-competitive solar assets.

This study examines the BOM manufacturing ecosystem through secondary research and industry stakeholder consultations. The secondary research included technical datasheets from domestic and global BOM manufacturers, journal articles, market surveys, trade statistics, and DGTR anti-dumping investigations. The resulting findings for each BOM component were further validated through discussions with relevant industry stakeholders.[14]

Limitations

1. Challenges related to storage and inventory across BOM components are not covered in the report.

2. The study primarily focuses on supply-side readiness. Accordingly:

    a. Investments required to upgrade BOM manufacturing processes, develop new or optimise existing raw material manufacturing processes, and incorporate additional testing certifications for improved quality assurance are not considered.

    b. The cost implications of sourcing raw materials from alternative sources, including domestic suppliers of virgin materials and entities supplying secondary raw materials from recycling, are not considered.

14. We consulted one stakeholder for solar glass; two stakeholders for aluminium frames; two for PV ribbons; four stakeholders for encapsulants; two stakeholders for backsheets; one stakeholder for junction box; one solar manufacturing equipment supplier, and one industry expert in reliability and performance testing.

2. Solar glass

Solar glass is a type of glass used in the manufacturing of solar PV modules. Within the industry, it is also referred to as low-iron solar glass, solar PV glass, high-transmission PV glass, tempered low-iron patterned solar glass, and heat-strengthened glass (MoCI 2025b). Solar glass protects the cells within a module, enhances module efficiency by maximising sunlight transmission to the cells, provides structural strength, and simplifies cleaning.

Market scenario

India's leading solar glass manufacturers include Borosil Renewables (6.5 GW), Vishakha Renewables (4 GW), Saint-Gobain (3 GW), Gold Plus (2 GW), Emerge Renewables (2 GW), Triveni Renewables (1.5 GW), and Gobind Glass (1 GW), bringing the country's cumulative nameplate production capacity to 20 GW per year[15] (Figure 2). These manufacturers, along with new entrants such as Reliance, Avaada, and Waaree Energies, are planning capacity expansions over the next two financial years, which are expected to increase cumulative capacity to 70 GW by March 2028. This capacity is expected to be sufficient to meet an annual solar module demand of approximately 67 GW. As of September 2026, India's solar glass manufacturing market was valued at USD 0.58 billion.[16]



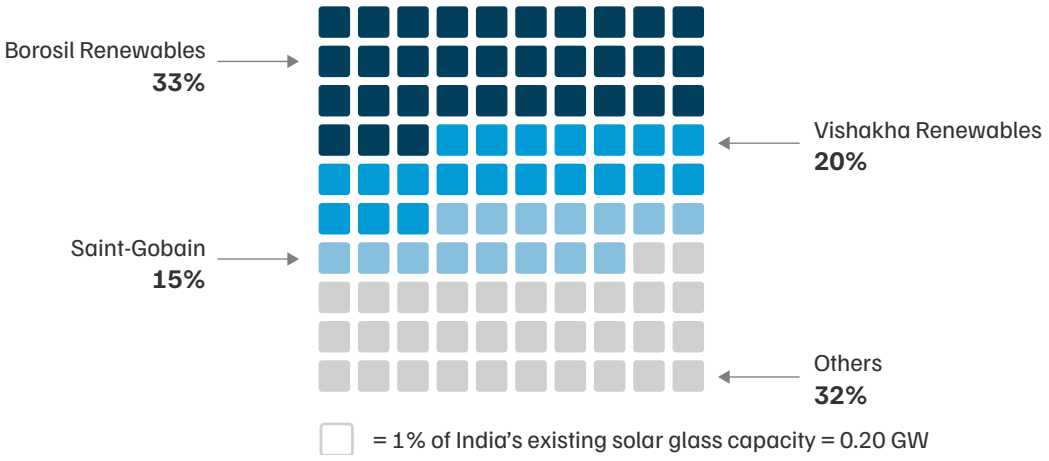
Image: Vishakha Renewables

Solar glass is the heaviest BOM component, accounting for more than 70% of a module's weight.

15. Based on September 2026 data from SAMA. Currently, 2 GW out of the 20 GW is not operational.

16. Calculations are provided in Annexure 1.

Figure 2. Domestic solar glass production is currently dominated by two manufacturers – Borosil Renewables and Vishakha Renewables



Source: Authors' compilation based on September 2026 data from Solar Ancillary Manufacturers' Association (SAMA).

Note: The percentages shown in the figure have been rounded to the nearest integer, bringing the total sum to exactly 100 per cent.

Raw materials for solar glass production

Solar glass production requires raw materials including silica sand, dolomite, limestone, soda ash, aluminium hydroxide, sodium antimonate, and coating liquid (Chowdhury et al. 2025). These raw materials must meet specific requirements. For instance, silica sand must have an iron content below 150 parts per million (ppm) (Chowdhury et al. 2025) and a grain size of 0.1–0.6 mm to ensure uniform melting characteristics (Sinonine 2021). It must also be sourced from high-purity quartz deposits with minimal contamination from other minerals. Other raw materials, including dolomite, limestone, and soda ash, aid the glass-melting process. Indian solar glass manufacturers import several of these raw materials. For example, Borosil Renewables imports dolomite from China, limestone from Egypt, and sodium antimonate and coating liquid from Europe (Borosil Renewables 2024). Similarly, Vishakha Renewables imports sodium antimonate, soda ash, and dolomite for its operations.[17]

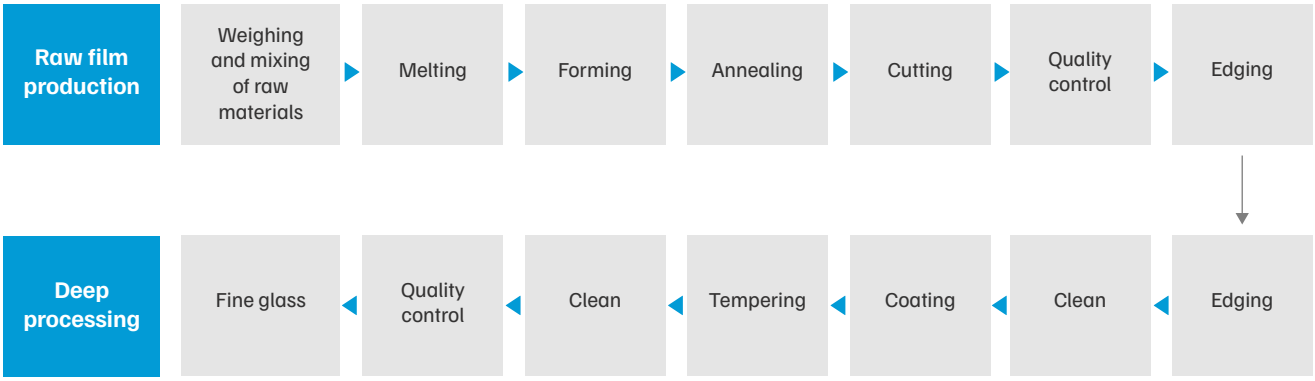
17. As per stakeholder consultation.

Manufacturing process of solar glass

After the raw materials are pre-processed to remove impurities, they are heated in a furnace at approximately 1,450°C to form molten glass. The furnace has a deep pool and stepped-bottom design to enable precise heating and a uniform composition. The molten glass from the furnace is then drawn through rollers to form flat sheets of glass, with the bottom roller creating a deep texture and the upper roller producing a smoother pattern. The sheets subsequently undergo annealing to remove internal stresses and increase their strength.

The glass sheets are then cut according to customer requirements, while their edges are ground and the sheets washed. An anti-reflective (AR) coating is applied to increase the transmission efficiency, depending on customer requirements. The glass is subsequently tempered. Physical tempering, commonly used in solar glass production, involves heating the glass above its softening point and rapidly cooling it to create compressive stress on the surface. This process can increase the strength of glass to 4–6 times that of conventional flat glass. Finally, the glass undergoes a quality inspection to ensure that it meets the required standards before packaging. Figure 3 illustrates the detailed manufacturing process.

Figure 3. Manufacturing of solar glass is a multi-step mechanical and thermal process



Source: Chowdhury, Tamal, Mohammad Dehghanimadvar, Nathan L. Chang, and Richard Corkish. 2025.

Trade, trade-related, and non-trade barriers

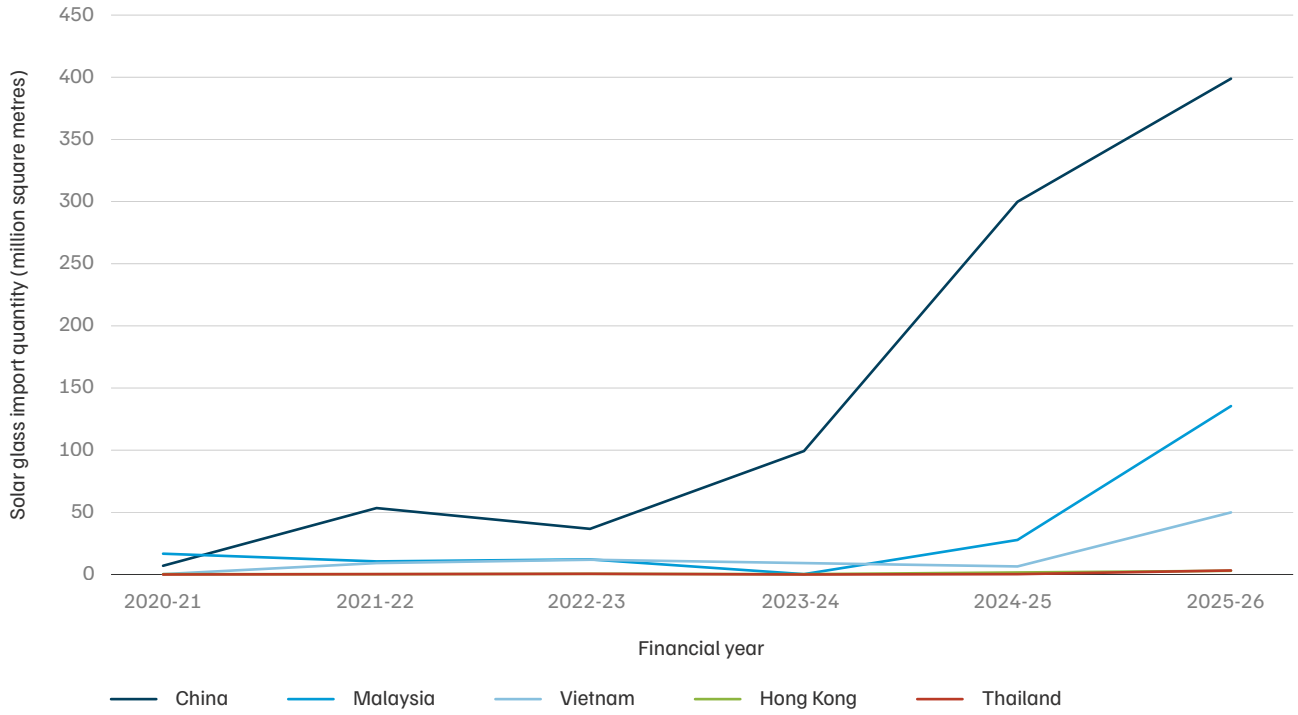
Trade barriers can protect domestic industry from unfair competition and help preserve jobs and strategic sectors. However, they can also raise prices, reduce consumer choice, and potentially weaken long-term competitiveness by limiting exposure to global competitive pressures.

The solar glass industry has a higher dependency on imports for several raw materials, including sodium antimonate, high-quality soda ash (sodium carbonate), dolomite, and limestone, on Europe and China, creating supply chain risks. Antimony is not mined in India (IBM 2021), while China has large antimony reserves and refining capacity, making imports from China more cost-effective for Indian manufacturers. The Union Budget 2026–27 removed the 7.5 per cent basic customs duty on sodium antimonate, reducing it to zero (GoI 2026). This lowers input costs for domestic solar glass manufacturers and improves their margins. However, according to stakeholder consultations, the cost reduction is not significant[18] and may therefore be insufficient to shield domestic manufacturers from import competition, particularly from low-cost exporting nations.

According to DGTR investigations, China, Malaysia, and Vietnam are among the largest exporters of solar glass to India, with imports from China peaking in FY2025–26, as shown in Figure 4 (MoCI 2025b). These imports are primarily recorded under Harmonised System (HS) code 70071900. However, the DGTR notes that solar glass is also imported under HS codes 70031990, 70051010, 70051090, 70052190, 70052990, 70053090, 70072190, 70072900, 70169000, 70200090, and 85414011 (MoCI 2025b).

18. As per stakeholder consultation.

Figure 4. China, India's largest solar glass exporter, faces the greatest cost impact from the imposed import duties



Source: System on India's Export Import (Data Bank – Tradestat), MoCI 2026a. Detailed information available in Annexure 3 – Table A5.

Note: Trade data presented in the figure are based only on imports under HS code 70071900, under which solar glass is primarily imported. Solar glass is also imported under other HS codes.

A key trade barrier is the countervailing duty (CVD) and anti-dumping duty (ADD) investigations conducted by the DGTR on textured toughened (tempered) glass, coated or uncoated, with light transmission greater than or equal to 90.5 per cent, a thickness less than or equal to 4.2 mm, and at least one dimension greater than 1,500 mm, primarily used in solar modules.

Countervailing duty (CVD)

In 2018, a CVD investigation was conducted on imports from Malaysia. The investigation determined that subsidised imports from Malaysia had increased significantly in volume, suppressing prices and undercutting domestic producers (MoCI 2026b). The domestic industry, represented by Borosil Renewables, was found to have suffered material injury, impacting its profitability, capacity utilisation, and cash flows. On 9 March 2021, the DGTR recommended and MoF imposed a definitive CVD for five years, until 8 March 2026, calculated as a percentage of the cost, insurance, and freight (CIF) value. Xinyi Solar incurred a CVD of 9.71 per cent, while all other Malaysian producers/exporters incurred a CVD of 10.14 per cent. The duty also applied to goods originating in Malaysia and exported through third countries, as well as third-country-origin goods exported from Malaysia.

In June 2025, the DGTR initiated a sunset review under Section 9(6) of the *Customs Tariff Act* to assess whether the expiry of the duty would likely result in the continuation or recurrence of subsidisation and injury to Indian producers. Based on initial review, the DGTR issued a notification on 7 December 2025 stating that the existing CVD would remain in force until 8 June 2026 (MoF 2025a). In March 2026, the DGTR recommended continuing the duty for another five years (MoCI 2026c). The Ministry of Finance (MoF) subsequently accepted this recommendation through *Notification No. 02/2026-Customs* (CVD), issued on 2 June 2026. The notification extended the CVD on textured tempered

glass from Malaysia for a further five years, until June 2031, at 9.71 per cent of the CIF value for Xinyi Solar (Malaysia) and SBH Kibing Solar New Materials and 10.14 per cent for other Malaysian producers (MoCI 2026b).

Similar investigations were conducted on imports from Vietnam. Exporters that responded to the investigation included Flat (Vietnam) Co Ltd and Flat (Hong Kong) Co Ltd (MoCI 2025c). The CVD is set at a maximum rate of USD 593 per metric tonne (MT) for imports from Flat (Vietnam) Co Ltd and USD 664/MT for imports from other producers.

Anti-dumping duty (ADD)

An ADD investigation into solar glass imports was conducted in 2024. The DGTR determined that dumped imports of textured tempered glass from China and Vietnam had increased significantly in volume and caused price undercutting and suppression, preventing the domestic industry from recovering costs and earning reasonable returns (MoCI 2025b). The domestic industry, represented by Borosil Renewables, was found to have suffered material injury, reflected in negative cash profits, profit before interest and tax (PBIT), and return on capital employed (ROCE), declining capacity utilisation, and rising inventories.

In its final findings dated 10 February 2025, the DGTR concluded that imports from China and Vietnam were dumped and had caused material injury to the Indian industry, warranting definitive anti-dumping duties to restore fair competition. Producer-specific duties were imposed by MoF, with Chinese exporters subject to duties of USD 658–677/MT, while Flat (Vietnam) Co Ltd and other Vietnamese producers were assigned duties of USD 570–664/MT (MoF 2025d). The duties also applied to relevant third-country routing, as clarified through a corrigendum to the preliminary duty table.

An earlier anti-dumping investigation was conducted in 2018 on imports from Malaysia, under which producers other than Xinyi Solar were charged with an ADD of USD 114.58/MT. The duty was not extended following the 2023 investigation (MoCI 2023a).

Despite these ADD and CVD measures undertaken by the government, structural changes in the global solar glass industry could affect the effectiveness of existing trade remedies. The solar glass supply chain has expanded from China into Southeast Asian (SEA) countries. For instance, Xinyi Solar has expanded its solar glass manufacturing base to Malaysia and Indonesia, bringing its total daily melting capacity to 22,600 tonnes as of June 2026 (Xinyi Solar 2026). Meanwhile, capacity expansion in China has stalled, with Xinyi Solar and China Southern Glass (CSG) pausing new furnace ignitions in early 2026 as domestic glass prices fell below cash costs (Mordor Intelligence 2026).

These shifts have direct implications for India's trade remedy framework. The May 2025 ADD on solar glass originating in or exported from China and Vietnam does not extend to Malaysia or other SEA nations. Additionally, imports constituting less than 3 per cent from World Trade Organization (WTO) member countries are automatically excluded from any ADD investigations (WTO 1994). If solar glass imports from individual SEA countries fall below the applicable threshold, this could affect the applicability of trade remedies.

Basic customs duty (BCD)

Under the Union Budget 2024–25, the government announced a 10 per cent basic customs duty on imported solar glass used to manufacture solar cells and modules, effective from 1 October 2024 (MoF 2025b). This tariff also applies to glass imports irrespective of their country of origin.

Quality control orders (QCO)

Solar glass used in modules must satisfy the material requirements stipulated under Indian Standard (IS) 14286, aligned with International Electrotechnical Commission (IEC) 61215, and IS/IEC 61730, as applicable. Bureau of Indian Standards (BIS) certification is also mandatory for safety glass used in solar applications,[19] which is covered under IS 2553 (Part 3): 2019 (BIS 2024). This standard ensures that safety glass meets the stringent quality and safety norms so that the functionality and durability of the PV modules is high. However, a QCO for IS 2553 (Part 3): 2019 has not yet been issued, unlike those for IS 2553 (Part 1):

> India has imposed a variety of duties - anti-dumping, countervailing, and a basic customs duty to safeguard domestic solar glass manufacturers.

19. Applications include solar modules and solar thermal systems.

2018 and IS 2553 (Part 2): 2019 (BIS 2020). Further, the MNRE requires retesting following any changes to the BOM or manufacturing processes and mandates that laboratories follow the latest notified versions of Indian standards from the date of notification (MNRE 2025). Any change in glass thickness or supplier, a routine cost-optimisation measure, triggers a full retesting cycle, imposing lead-time costs of several months and testing fees that could be disproportionate for smaller or emerging domestic glass producers.

Key risks identified for Indian manufacturers

1. **Manufacturing risks**:[20] Glass–glass variants of bifacial modules use 2 mm solar glass on both sides instead of the standard 3.2 mm glass used in monofacial modules to improve light transmittance. Tempering thinner glass requires specialised tempering lines with tighter process control and advanced handling systems. As such, utilising the same tempering lines as in the manufacturing of 3.2 mm glass results in semi-tempered glass sheets. Such inadequate process optimisation can also increase glass breakage during tempering, handling, and module assembly (PV Magazine India 2026), increasing production losses, reducing yields, and raising production costs for domestic manufacturers.

2. **Quality assurance risks**:[21] Solar glass standards followed by domestic manufacturers such as Borosil Renewables are comparable to those followed by Chinese suppliers such as Fulong and Migo. However, Migo conducts additional testing for anti-reflective (AR) coatings, including EN[22] 1096-2 surface durability tests and ASTM adhesion/hardness tests, which are not specified in the datasheets of Borosil Renewables and Vishakha Renewables (Migo Glass n.d.; Borosil Renewables 2020; Vishakha Renewables n.d.). Further, a QCO for IS 2553 (Part 3): 2019 has not yet been issued by the BIS, as stated earlier.

3. **Financial risks**:[23]

a. Raw materials account for a significant share of solar glass manufacturing costs. For instance, raw material costs accounted for 25.6 per cent and 23.5 per cent of Borosil Renewables' costs in FY2024 and FY2023, respectively (Borosil Renewables 2024). Prices of key raw materials, such as soda ash, silica sand, limestone, and dolomite, are linked to global commodity markets and are therefore subject to frequent price fluctuations. Volatility in these input costs can significantly affect production expenses, particularly as soda ash and silica constitute a large share of raw material costs.

b. Solar glass manufacturing is highly energy-intensive, with 1 tonne of molten glass requiring approximately 3,800–4,800 megajoules (MJ) of energy (Chowdhury et al. 2025). As a result, any fluctuations in the price of natural gas used in manufacturing can significantly increase manufacturers' operating expenses and production costs.

4. **Regulatory risks**:[24]

a. As solar glass is imported under multiple HS classifications, it creates serious enforcement and policy challenges. This practice obscures the true volume and value of imports, undermines the accuracy of trade statistics, and makes it difficult for authorities to effectively implement trade remedies such as anti-dumping or countervailing duties, which are typically linked to specific HS codes. It also enables duty evasion and regulatory arbitrage, allowing importers to avoid applicable tariffs, quality controls, or safeguard measures, while placing compliant domestic manufacturers at a competitive disadvantage. More broadly, fragmented classification weakens customs monitoring, complicates injury assessments in investigations, and dilutes the effectiveness of industrial policy by allowing circumvention through misdeclaration rather than reflecting the actual movement of the subject goods.

20. Manufacturing risks are related to negligence in optimising manufacturing processes impacting production loss, reduced yields, poor quality outputs, and overall loss in competence.
21. Quality assurance risks are related to the failure in adoption of certain testing standards for product quality control which are followed by either global counterparts or domestic peers.
22. EN - Europäische Norm (German) or European Standard (English)
23. Financial risks are related to the cost-competency of manufacturers, leading to higher production costs and reduced profit margins.
24. Regulatory risks are those that put manufacturers at a competitive disadvantage due to uncertainty in regulatory or trade policies that include HS code classifications or antidumping duty orders.

b. Certification-linked BOM lock-in can create a regulatory risk for solar glass manufacturers, as any substitution requires full module recertification, triggering costly and time-intensive testing cycles borne by module manufacturers. Additionally, the risk of temporary loss of ALMM eligibility during requalification discourages switching, effectively excluding new domestic glass suppliers despite competitive pricing.

Recommendations

1. **Manufacturers should enhance solar glass quality by adopting robust manufacturing practices and strengthening testing protocols to produce solar glass at par with international standards**: Manufacturers should utilise advanced tempering lines to produce fully tempered thinner glass sheets. Additionally, domestic manufacturers should adopt testing protocols such as EN 1096-2 for surface durability and ASTM D3359 for adhesion testing to confirm the quality and adhesion of AR coatings on solar glass. Manufacturers should also install fully automated inspection systems in their production lines to detect defects, reduce operational losses, and improve customer satisfaction.

2. **The Department for Promotion of Industry and Internal Trade (DPIIT), Ministry of Commerce and Industry in consultation with the BIS should issue a QCO for solar glass - IS 2553 (Part 3): 2019** to ensure uniform quality control for all domestic solar glass production: The BIS should work together with solar glass manufacturers and module manufacturers to establish testing protocols under this standard. The QCO should be released by June 2027, to be made effective from January 2028.

3. **Manufacturers should build a local ecosystem for raw material procurement to reduce exposure to global price shocks and create a more resilient supply chain**:

a. Manufacturers should explore procuring raw materials domestically to strengthen resilience, ensure more stable lead times, and reduce exposure to currency fluctuations. For example:

   i. Sodium antimonate can be procured from local sources such as Chemico Chemicals (Chemico Chemicals n.d.), which produces sodium antimonate as a refining agent for the glass industry. This represents a potential opportunity for domestic sourcing of the raw material, subject to the required quality specifications.

   ii. Limestone can also be procured locally, given India's vast reserves (Indiatlas 2025). However, the current constraint is the availability of low-iron, high-purity grade limestone that is suitable for solar glass production.

b. Manufacturers should also adopt circular practices to secure raw material supplies and increase resource efficiency. Before melting the mixture of raw materials, manufacturers add glass cullet (recycled glass) to this mixture to lower its melting point, resulting in a reduced consumption of natural gas (Borosil Renewables 2024). A potential pathway to source this glass cullet is through solar waste recycling. Recycled glass cullet can meet 40 per cent of the solar glass demand required for manufacturing new modules between 2026 and 2047 (Tyagi et al. 2025). The solar industry should promote recycling of solar waste to diversify sources of glass cullet. Further, glass manufacturers should share their requirements with solar waste recyclers to enable the development of processes for recovering high-quality glass cullet. Finally, manufacturers producing antimony-free solar glass must take necessary steps to ensure that recycled glass is antimony-free.

4. **Manufacturers should procure energy from renewable sources and create backups for natural gas supply to reduce production costs**: Manufacturers should procure electricity from open access renewable energy generation facilities, such as solar–wind hybrid projects, to reduce electricity costs and, consequently, overall production costs, thereby increasing the profit margins of manufacturers. For instance, Borosil Renewables invested in setting up a 16.5 megawatt (MW) solar–wind hybrid project to procure clean energy via open access, with estimates suggesting savings of Indian rupee (INR) 170 million (USD 1.95 million) annually (Mercom India 2025a). Further, manufacturers should create backups for a steady natural gas supply by setting up on-site storage units or diversify the gas supply-chain through local sourcing to avoid

> Advanced tempering, uniform quality standards, and local raw materials can make Indian solar glass globally competitive.

procuring it at higher costs during supply chain disruptions when force majeure is invoked even in long-term contracts. This could help keep stabilise production costs.

Additionally, manufacturers can explore electric melting furnaces instead of gas-fired furnaces for solar glass production[25] (Li et al. 2025). When coupled with a renewable electricity supply, this can prove to be a cost-saving option.

5. **The Central Board of Indirect Taxes and Customs (CBIC) should introduce a dedicated HS classification for solar glass to strengthen customs enforcement, prevent misclassification, and safeguard the interests of domestic manufacturers before the Union Budget 2027–28**: The CBIC should coordinate with the Directorate General of Foreign Trade (DGFT) and the DGTR to introduce and enforce a dedicated HS code specifically for solar glass. This would improve the transparency of trade data, enable accurate tracking of import volumes, and strengthen the implementation of trade remedies such as anti-dumping and countervailing duties put forth by the DGTR.



Image: Vishakha Renewables

The demand for thinner solar glass – 2 mm has risen sharply due to increased adoption of glass-glass modules over glass-backsheet modules.

25. Electric melting furnaces come with their own challenges such as limited capacity and lifetime (Zier et al. 2021).

3. Aluminium frames

Aluminium frames in solar PV modules are structural components that provide mechanical strength and protection to the modules. They are typically made from anodised aluminium, which offers corrosion resistance and durability in outdoor environments. These frames help secure the entire PV laminate and glass layers, maintaining the integrity of the module during transport, installation, and operation. Aluminium's lightweight characteristics make it ideal for rooftop and large-scale solar applications, as it reduces the overall system weight.

Market scenario

Domestic aluminium frame manufacturers include Vishakha Renewables (12 GW), H&H Aluminium (6 GW), Rayzon (4 GW), Solnex Renewables (4 GW), Ralpro Industries (4 GW), Aluflex (4 GW), Shanti Greentech (3 GW), Alpex Solar (2 GW), Atom Extrusion (2 GW), Global Aluminium (2 GW), JM Aluminium Extrusion (2 GW), La Reliant (2 GW), Satya Metal Industries (2 GW), Sadashiv Group (2 GW), Sudarshan Aluminium (1 GW), Vinitech Metals (1 GW), MR Industries (1 GW), Angel Extrusion (1 GW), Ultra Aluminium (1 GW), Avirat Metal (1 GW), and PAM Aluminium (1 GW), along with a few others with a cumulative capacity of 8 GW[26] (Figure 5). This brings the combined capacity to 66 GW per year. In addition, Insolation Energy and Premier Energies are planning to set up their own aluminium frame production facilities. Commissioning these facilities, along with planned expansions by existing players, would raise the total manufacturing capacity to 118.5 GW per year by March 2028, enough to meet the country's annual module demand of approximately 67 GW. As of September 2026, the domestic aluminium frame manufacturing market was valued at approximately USD 1.56 billion.

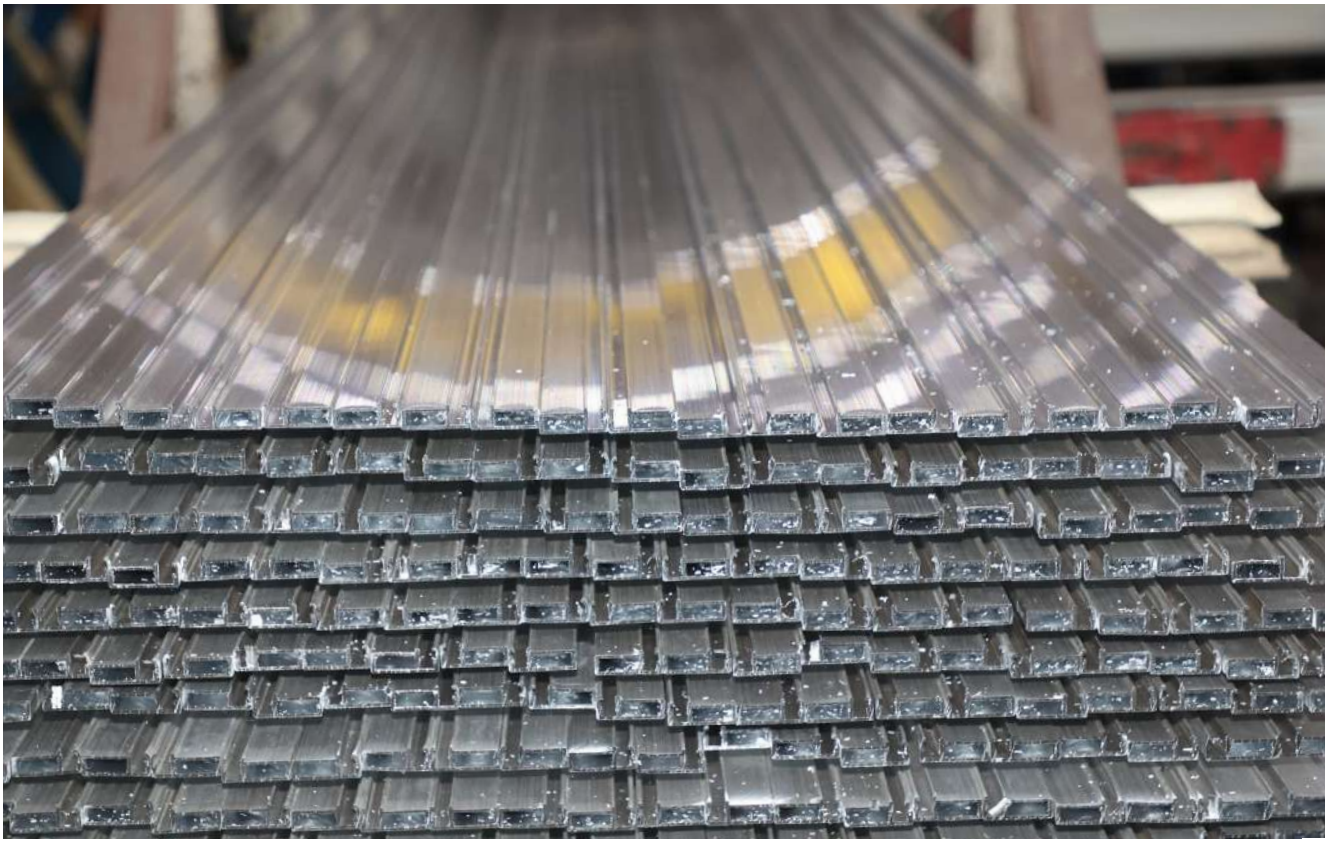
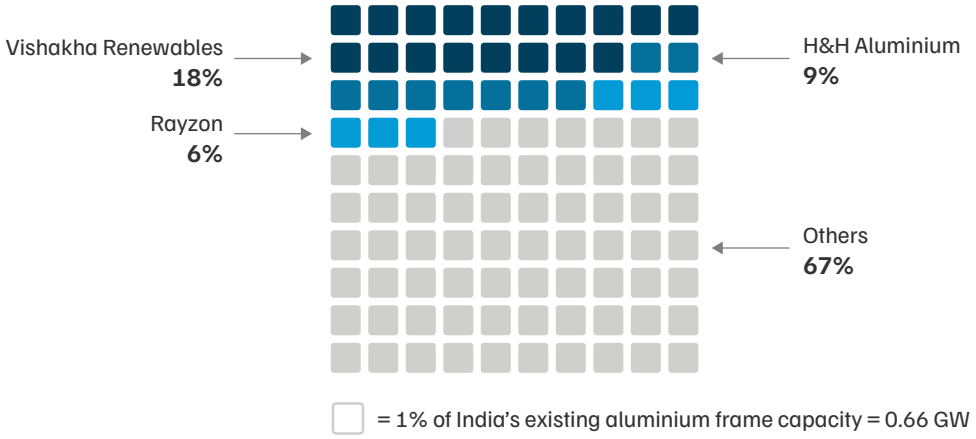


Image: Vishakha Renewables

Aluminium frames account for approximately 10% of a solar module's weight.

26. As per September 2026 data from SAMA. Currently, 18 GW out of the 66 GW is not operational.

Figure 5. Vishakha Renewables forms almost one-fifth of all aluminium frame production capacity currently



Source: Authors' compilation based on September 2026 data from Solar Ancillary Manufacturers' Association (SAMA).

Note: The percentages shown in the figure have been rounded to the nearest integer, bringing the total sum to exactly 100 per cent.

Manufacturing process of aluminium frames

The process begins with the selection of high-quality raw materials. Aluminium frames for solar modules are typically manufactured using high-grade 6063 and 6005 aluminium alloys in T5 or T6 temper, which offer an optimal balance of strength, corrosion resistance, and machinability, essential for durable and precise frame construction.

Aluminium extrusion is the next step and involves melting the high-grade aluminium and driving it through extrusion dies to achieve the desired cross-sectional profiles tailored for solar modules. The extruded profiles are then polished using processes such as shot blasting to remove any sharp edges, ensuring a clean and smooth surface. To enhance durability and corrosion resistance, the frames undergo surface treatment and coating processes, such as anodising or powder coating, which also improve their aesthetic appeal. These treatments apply a protective oxide layer to provide the aluminium frames with corrosion resistance properties that last throughout their operational life, safeguarding them against harsh climatic conditions. The extruded profiles then undergo precision cutting and machining using advanced milling and drilling techniques to refine their dimensions and create detailed features such as mounting holes and assembly interfaces.

Throughout production, rigorous quality assurance protocols are applied to verify dimensional accuracy, material integrity, and surface finish, maintaining adherence to stringent industry standards. Finally, packaging and logistics operations are carried out to ensure that the frames are securely packed and safely transported to their destinations without damage.



Image: Vishakha Renewables

The domestic aluminium extrusion industry is operating at a lower utilisation rate due to high fuel prices, gas shortages, shortages in aluminium scrap, and lower economies of scale.

Trade, trade-related, and non-trade barriers

Domestic aluminium frame manufacturers face elevated input costs (GTRI 2026) because domestic raw material producers, such as the National Aluminium Company Ltd (NALCO) and Bharat Aluminium Company Ltd (BALCO), price aluminium at global benchmark rates plus the equivalent of the import duty. This 7.5 per cent import duty on unwrought aluminium effectively acts as a price floor that domestic buyers pay even when sourcing locally.

As of July 2026, the global price of PV frames, according to the Shanghai Metals Market, was USD 3,242/MT (Shanghai Metals Market 2026a). During the same period, the price of aluminium ingots sold by BALCO and Vedanta Ltd ranged from USD 3,575 to USD 3,775/MT, while aluminium wire rods and billets ranged from USD 3,680 to USD 3,770/MT (BALCO 2026). Similarly, NALCO prices for aluminium ingots ranged from USD 3,762 to USD 3,879/MT, while billet prices ranged from USD 3,809 to USD 3,873/MT (NALCO 2026). This indicates that raw materials sold domestically cost more than finished products sourced from the international market, creating price pressure for domestic aluminium frame manufacturers.[27] Higher domestic raw material prices also lead PV frame manufacturers to source through countries with which India has free trade agreements (FTAs).

Additionally, under the current GST regime, if components are supplied as part of a composite solar power-generating system, 5 per cent GST applies to 70 per cent of the contract value; if components are supplied and invoiced separately, they may be treated as a mixed supply and attract different GST rates (MoF 2025c). Specifically, aluminium frames (HS 7604) are taxed at 18 per cent GST when invoiced separately (MoF 2017). Thus, when a frame manufacturer generates an invoice by weight (i.e. as an independent aluminium product), it falls under the standard 18 per cent GST classification and can claim input tax credit (ITC). When invoiced as part of a set or system, the composite supply rules may suppress or complicate this. This is a documented case of GST arbitrage in the solar sector.

The origin of raw material inputs also points to a vulnerability in the BOM supply chain. While primary smelted aluminium has been heavily routed through Vietnam, the country had no primary aluminium smelter until the Dak Nong project, Vietnam's first, which, as of June 2026, was moving towards trial operations and production, with an annual capacity of 450,000 tonnes (AL Circle 2026). This raises concerns about the circumvention of imports through insufficient value addition. With the India–Association of Southeast

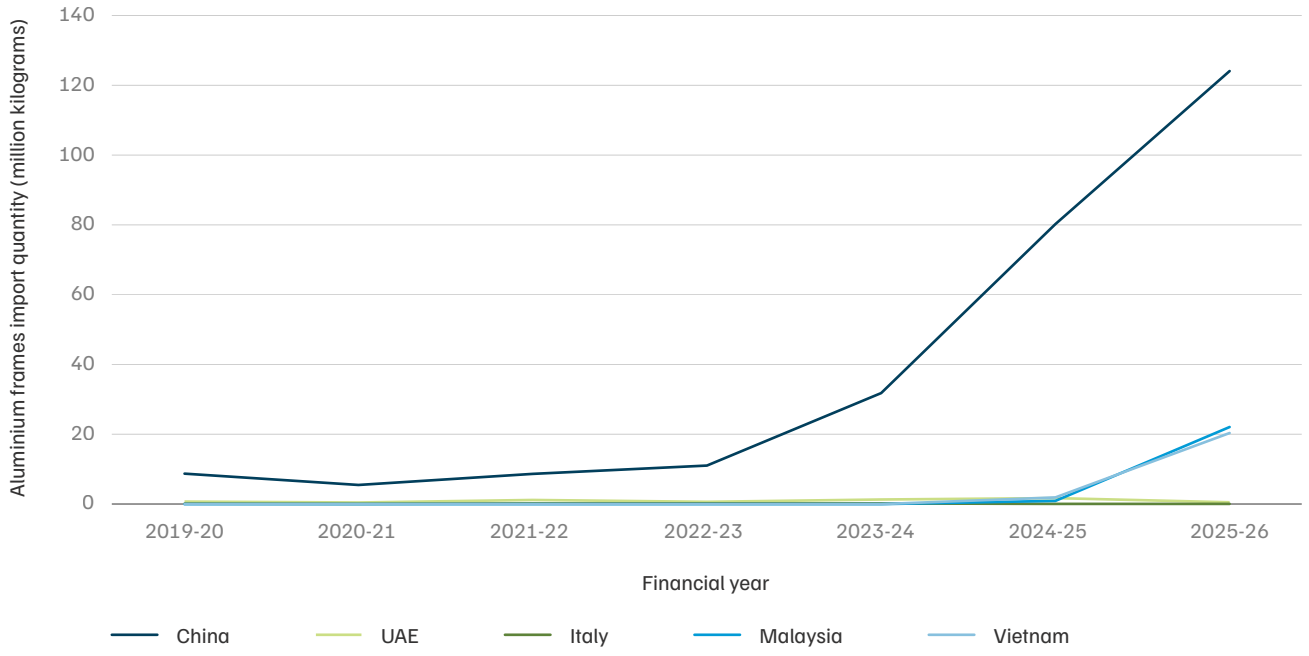
27. Our stakeholder consultation reveals the same.

Asian Nations (ASEAN) FTA, which is currently under renegotiation, allowing zero per cent import duty on finished aluminium products (WTO Center 2016), this potentially creates an unfair advantage for importers of aluminium frames and impacts the competitiveness of the domestic industry.

These origin concerns are further compounded by classification ambiguities, as the lack of a single definitive HS code for aluminium frames creates additional opacity in tracking the true source and volume of imports. As aluminium frames are imported under different HS codes to circumvent anti-dumping and customs duties, there is also uncertainty about which HS codes accurately reflect the trade in aluminium frames. Aluminium goods are largely imported under HS code 7604. However, the DGTR also notes that aluminium frames are imported from several countries, namely China, Malaysia, Vietnam, the United Arab Emirates, and Italy, under HS codes 76109010, 76109030, 76109020, 76109090, 76161000, 76169910, and 76169990 (MoCI 2024a). China is the country's largest source of imports, as shown in Figure 6.

The DGTR carried out an ADD investigation into dumped imports of anodised aluminium frames for solar modules from China (MoCI 2026d). In its final findings dated 29 June 2024, the DGTR concluded that aluminium frames from China were being dumped in India and that such dumping had caused material injury and materially retarded the establishment of the domestic industry. The DGTR therefore recommended, and in 2024, MoF imposed a definitive anti-dumping duty on imports of anodised aluminium frames for solar modules from China for five years, with producer-specific duties ranging from USD 403/MT to USD 577/MT (MoF 2024b). The ADD is levied such that a lower duty is imposed for cooperating exporters and a higher residual duty for all other Chinese producers/exporters, with the duties also applying to third-country routing where applicable.

Figure 6. China is the largest exporter of aluminium frames to India, attracting higher anti-dumping duties



Source: System on India's Export Import (Data Bank – TradeStat), MoCI (2026a). Detailed information is provided in Annexure 3, Table A6.

Note: Trade data presented in the figure are based on imports under only one HS code, 76109030, as aluminium frames for solar modules are mainly imported under this specific HS code. These frames are also imported under other HS codes. Additionally, the trade data are representative and include imports of other aluminium goods under this HS code, such as plates, rods, profiles, and tubes.

The DGTR investigation effectively strengthens domestic aluminium frame manufacturers by imposing targeted anti-dumping duties that narrow the price gap created by Chinese imports. By differentiating duties across exporters and covering third-country routing, it limits circumvention risks and provides sustained protection to support domestic industry growth and capacity expansion.

Key risks identified for Indian manufacturers

The aluminium extrusion industry in India, with a total manufacturing capacity of 3.5 million tonnes per year, operates at a capacity utilisation factor (CUF) below 57 per cent, equivalent to approximately 2 million tonnes per year (BigMint 2025). This is due to high fuel costs, gas shortages (Rediff 2026), shortages in aluminium scrap, and lower economies of scale. Many extrusion units reported production cuts ranging from 30 to 70 per cent as of March 2026 (Balaji Aluminium Extrusions 2026). Given the similarity in production processes, solar aluminium frame manufacturers could be vulnerable to similar production cuts and underutilisation due to these challenges, leading to curtailment of existing manufacturing capacity.

Further, according to the Aluminium Extrusion Manufacturers Association of India (ALEMAI), local players face rising import competition and high import duties on raw materials, while imports of finished products benefit from duty-free access under FTAs. Such scenarios threaten their competitiveness against global players. Other risks are highlighted as follows:

1. **Manufacturing risks**:

a. Anodising thickness for frames is typically 10–15 micrometres. This thickness can vary due to numerous factors, such as extrusion conditions, surface preparation, electrical contact, and process control during manufacturing. Variations in thickness can negatively impact the frame's corrosion resistance, mechanical durability, and aesthetics, resulting in poor-quality finished products.

b. Module manufacturers have observed scratches on finished aluminium frames[28], resulting in poor product quality. These scratches, caused by improper handling of the frames during packaging and transportation, can reduce the quality of finished frames and undermine buyer confidence in locally manufactured products.

2. **Technological risks**:[29] With continuous technological innovation in the PV industry, frames made from plastic and composite materials are also gaining interest because of their distinct advantages over aluminium frames (PV Magazine India 2025). These include lower weight, increased corrosion resistance, lower thermal conductivity, and lower thermal expansion rates of composite frames. According to the *International Technology Roadmap for Photovoltaics* (ITRPV), the global market share of plastic and composite frames was less than 2 per cent in 2025 and is estimated to reach 7 per cent by 2035 (VDMA 2025). Aluminium frame manufacturers may therefore face a growing risk of market share erosion and margin pressure in the long run.

3. **Financial risks**: Aluminium has experienced increased volatility in raw material prices globally, resulting in uncertainty among frame manufacturers. Similarly, domestic aluminium scrap prices increased by 16 per cent year on year, from USD 2,070 per tonne in the first quarter of the calendar year 2025 (Q1CY2025) to USD 2,400 per tonne in Q1CY2026, due to tighter domestic availability and firm import parity (BigMint 2026). Such price volatility increases production costs and reduces manufacturers' profit margins.

4. **Regulatory risks**: Aluminium frames do not have a dedicated HS code. Without a specific HS classification, the product tends to be imported under multiple alternative tariff headings, which fragments trade data and obscures the true scale and pricing of imports. This makes it difficult for customs authorities and policymakers to accurately monitor volumes, assess market trends, or detect under-invoicing and misdeclaration. It also weakens the effectiveness of trade remedies, such as anti-dumping or countervailing duties, because importers can shift declarations to neighbouring codes to avoid duties, quality controls, or other regulatory requirements. This puts compliant domestic manufacturers at a competitive disadvantage.

> Domestic frame manufacturers face high import duties on aluminium, while imports of finished products benefit from duty-free access under FTAs.

28. As per stakeholder consultations.

29. Technological risks are related to the lag in adopting new technologies, gaining popularity in the international market and offered by global and other domestic competitors.

Recommendations

1. **Manufacturers should improve process control during production to strengthen product quality and ensure international-grade outputs**. Process control during anodising should be strengthened to ensure consistent coating thickness within the 10–15 micrometre range. This can be achieved by improving surface preparation, maintaining stable electrical contact during anodising, and integrating automated monitoring systems into manufacturing lines.

2. **Manufacturers should expand their product portfolios to include products made from advanced materials to avoid market obsolescence**. The diversified product portfolio should include frames made from composite materials and galvanised steel.[30] This would allow manufacturers to cater to the preferences of module manufacturers opting for such components. At the same time, the salvage value of composite frames is considerably lower than that of aluminium frames.[31] Alternatively, manufacturers could invest in research and development of frames made from the same base material, aluminium, to make them a more attractive option for buyers in terms of durability and cost competitiveness.

3. **Manufacturers should secure raw materials through long-term contracts for financial de-risking**.

a. **Frame manufacturers should secure key raw materials, such as aluminium billets, through long-term supply contracts to reduce price volatility and improve financial stability**. Establishing strategic procurement agreements with domestic producers such as NALCO and BALCO can help ensure a reliable supply of aluminium, provided these agreements are structured with benchmark-linked pricing to avoid locking manufacturers into the current domestic premium. Domestic sourcing can also reduce exposure to global supply disruptions and currency fluctuations. Frame manufacturers should ensure that the quality of aluminium procured is suitable for producing aluminium alloys such as 6063 and 6005. However, raw materials procured from domestic sources are currently priced higher than global benchmarks, a key barrier that requires urgent interventions, such as easing duties on frame-grade aluminium inputs to narrow the cost gap faced by domestic frame manufacturers.

b. **Aluminium frames can be recovered from decommissioned solar modules, repaired, anodised, and reused in new PV modules**. Estimates suggest that recycling solar modules can meet 50 per cent of the aluminium demand for producing new modules between 2026 and 2047 (Tyagi et al. 2025). Using recycled aluminium scrap can strengthen resilience against financial risks arising from fluctuations in global aluminium prices.

4. **The CBIC should introduce a dedicated HS classification for aluminium frames used in solar modules to strengthen customs enforcement and prevent misclassification before the Union Budget 2027–28**: It should coordinate with the DGFT and DGTR to introduce and enforce a dedicated HS code specifically for aluminium frames used in module manufacturing. This would improve trade-data transparency, enable accurate import tracking, and strengthen the DGTR's implementation of trade remedies.



Image: Vishakha Renewables

Aluminium is not only used in the production of frames in solar modules, but also used in the manufacturing of mounting structures in solar PV systems.

30. First Solar, a thin-film module manufacturer, is already using galvanised steel for its back rail mounting system that it procures locally (First Solar n.d.).

31. As per stakeholder consultation.

4. Photovoltaic ribbons

Photovoltaic ribbons are tinned copper conductive strips or wires used to interconnect solar cells and carry electrical current within a solar module. They form the essential electrical pathways between cells, known as interconnect ribbons or tabbing ribbons, and between cell strings and the junction box, known as busbars. These two types of ribbons differ in thickness and width. Busbars have a thickness of 0.07–0.5 mm and a width of 3–8 mm, depending on the module size. In comparison, interconnect ribbons have a diameter of 0.24–0.32 mm, depending on the number of busbars (10-16), for round ribbons,[32] and a thickness of 0.07–0.2 mm and a width of 1–3 mm for flat ribbons (Raytron 2024).

A high-quality PV ribbon has low electrical resistance for efficient current transfer, improved corrosion resistance against environmental factors such as moisture and humidity, good solderability to enable reliable connections (Valeo n.d.), mechanical flexibility during the thermal expansion of modules, and an optimal reflective surface coating to minimise optical shading losses. Other important parameters include yield strength, camber, elongation, and winding of the ribbons (Ulbrich n.d.).

Market scenario

Domestic PV ribbon manufacturers include Dhash PV (18 GW), Valeo Products (12 GW), AB Industries (5 GW), Sumati Electronics (5 GW), Sekhani Industries (5 GW), Geba Cables and Wires (2 GW), Priti Cables (2 GW), Vidya Wires (2 GW), Oswal Solar Structure (1 GW), GK Winding Wire (0.5 GW), Best Wire (0.5 GW), Chandresh Cables (0.5 GW), K.M. Gandhi (0.5 GW), and Swipe India (0.25 GW)[33] (Figure 7). This brings the cumulative manufacturing capacity to 54.25 GW. Planned expansions by these manufacturers would increase the manufacturing capacity to 126 GW by March 2028. As such, the cumulative manufacturing capacity for PV ribbons is expected to be sufficient to meet the country's annual module demand of approximately 67 GW. As of September 2026, the domestic PV ribbon manufacturing market was valued at approximately USD 0.52 billion.

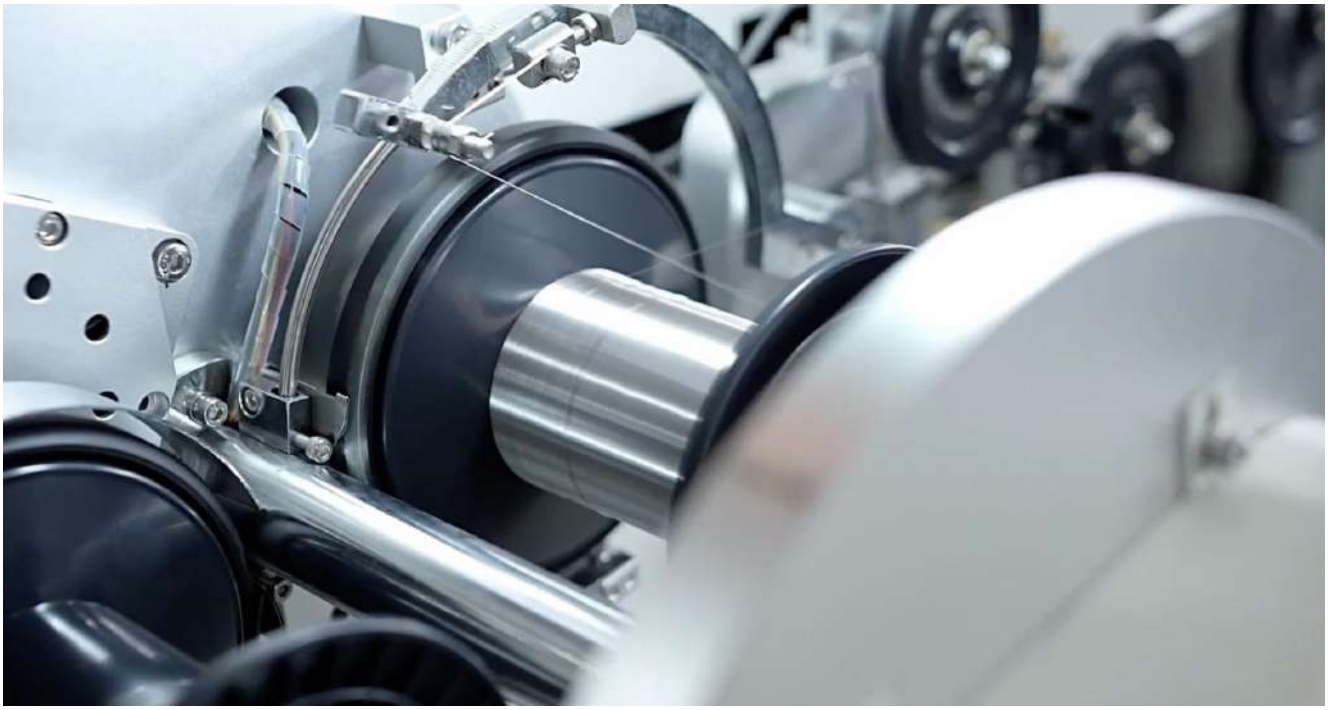


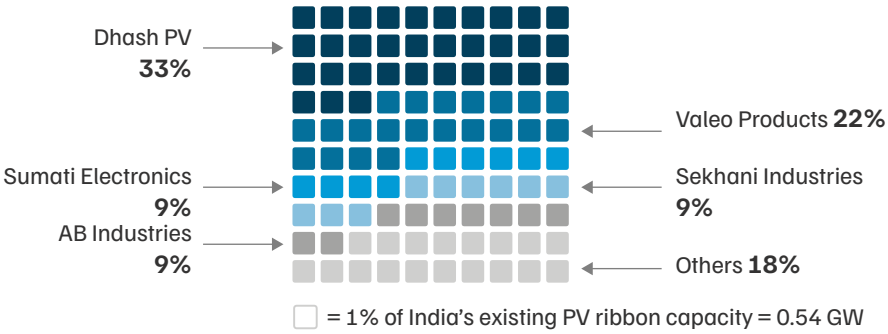
Image: Dhash PV Technologies

PV ribbons use different solder coating materials based on customer requirements, such as tin/lead, tin/silver/lead, and even lead-free alloys like tin/bismuth.

32. As per stakeholder consultation.

33. As per September 2026 data from SAMA.

Figure 7. Dhash PV and Valeo Products account for more than half of the domestic PV ribbon manufacturing capacity



Source: Authors' compilation based on September 2026 data from Solar Ancillary Manufacturers' Association (SAMA).

Note: The percentages shown in the figure have been rounded to the nearest integer, bringing the total sum to exactly 100 per cent.

Manufacturing process of PV ribbons

The first step is to select the appropriate raw material for manufacturing PV ribbons. High-grade copper, such as oxygen-free copper (OFC) or electrolytic tough-pitch copper (ETP), is used as the raw material. Copper rods made from these base materials are then used to manufacture PV ribbons.

These copper rods are drawn through wire-drawing machines to produce copper wires with specific diameters. The wires are then rolled to flatten them into rectangular cross-section ribbons according to the desired dimensions. The ribbons subsequently undergo an annealing process to relieve internal stresses and improve ductility, followed by surface treatment processes for cleaning. Once cleaned, the PV ribbons are coated with tin or other metals, such as lead or silver, depending on customer requirements. Processes used in this stage include hot-dip tinning or electroplating, depending on the financial constraints of manufacturers. The ribbons may also undergo anti-oxidation treatment or flux coating to improve their shelf life.

The finished products undergo a quality inspection to ensure that they meet industry standards. Finally, the PV ribbons are wound onto spools and packaged for delivery to customers. The winding process must be carefully implemented to avoid tangles or changes in ribbon tension.

Table 1. PV ribbons made of copper-clad aluminium (CCA) are gaining popularity across the PV industry due to their distinct advantages over pure copper ribbons

Base material	Advantages	Limitations
Aluminium	• Cost savings • Lightweight • Supports reduced use of copper • Lower carbon footprint than copper	• Lower conductivity • Lower mechanical strength • Higher thermal expansion coefficient
Copper-clad aluminium	• Better conductivity than pure aluminium • Better corrosion resistance • Cost savings	• A thin or uneven copper layer can lead to increased thermal stress and increased corrosion

Source: Greenshine. n.d. "Is the Conductivity of Copper Clad Aluminium PV Ribbon Much Different from Pure Copper Ribbon?" Greenshine.



Image: Dhash PV Technologies

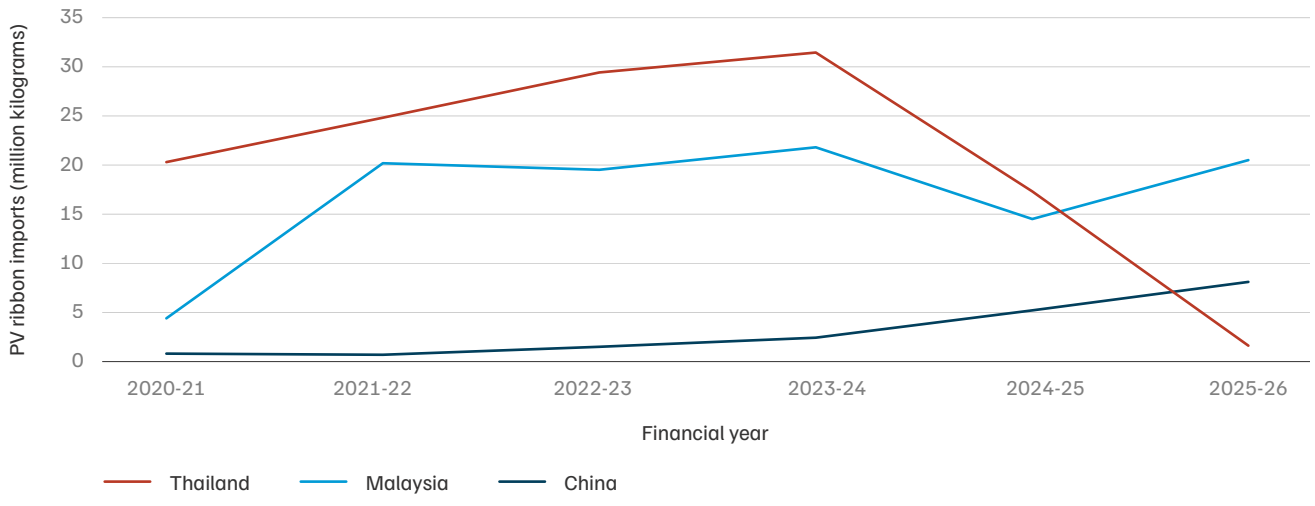
PV ribbon design has moved on from traditional flat strips of tinned copper to round wires for new age high-efficiency solar modules.

Trade, trade-related, and non-trade barriers

Copper ribbons for solar cells and busbars are mainly sourced from Thailand, Malaysia, and China (Figure 8). On 23 July 2024, the government announced a 5 per cent BCD on "tinned copper interconnects" for manufacturing solar cells or modules, effective from 1 October 2024 (MoF 2024a). Copper ribbons are traded under HS codes 7407 (rods) and 7408 (copper wire), titled "copper and articles thereof: copper bars, rods and profiles" and "copper and articles thereof: copper wire", respectively (MoCI 2015). They are also imported under other HS code families, such as 7409.

No ADD/CVD investigations have been initiated for PV ribbons due to their classification under generic copper wire HS codes and high price sensitivity, making trade remedies less targeted and less effective. While ADDs are not the primary instrument here, supply chain measures and incentives for ancillary manufacturing help Indian firms gradually substitute imports.

Figure 8. Copper ribbons are largely imported from Thailand, Malaysia and China



Source: System on India's Export Import (Data Bank – TradeStat), MoCI (2026a). Detailed information is provided in Annexure 3, Table A7.

Note: Trade data presented in the figure are based on imports under only one HS code, 74081990, as PV ribbons are mainly imported under this specific HS code. PV ribbons may also be imported under other HS codes. Additionally, these trade data are representative and include imports of copper wires used in other applications.

Basic customs duty (BCD)

The Union Budget 2026–27 modified and extended the BCD exemption on copper wire and copper rods used for manufacturing PV ribbons (MoF 2026a). The scope of this BCD exemption is defined as "Copper wire of refined copper of which the maximum cross-sectional dimension exceeds 6 mm or copper rods of refined copper, for the manufacture of photovoltaic ribbon or tinned copper interconnect or cell interconnect or string interconnect or the photovoltaic connect or photovoltaic ribbon or solar ribbon for manufacture of solar photovoltaic cell or modules", falling under HS 7407 and 7408. This addresses the input cost problem in principle for domestic ribbon manufacturers, who can now draw copper wire at a lower landed cost.

Key risks identified for Indian manufacturers

1. **Technological risks**:

a. With module manufacturers seeking higher efficiencies, ribbon manufacturers such as Telison, China (Telison n.d.), and Ulbrich Solar Technologies, USA (Ulbrich n.d.), have developed ribbon technologies designed to reflect secondary reflection so that modules can obtain greater optical gain. This is achieved through a V-groove structure incorporated into the ribbons. Currently, only Sumati Electronics supplies such reflective PV ribbons in India (Sumati Electronics n.d.a). Failure to adopt such newer and innovative technologies can result in ribbon manufacturers becoming obsolete.

b. Similarly, next-generation module technologies such as HJT and perovskites utilise low-temperature PV ribbons. The coatings of these ribbons are made from a combination of tin, bismuth, and silver alloys. Such ribbons help reduce thermal stress during the soldering process, minimising damage to sensitive cell types such as HJT and perovskites and improving module durability. Only two manufacturers, Dhash PV[34] and Sekhani Industries, currently provide such low temperature PV ribbons (Sekhani 2024). As Indian module manufacturers start adopting HJT and perovskites at scale, demand for these ribbon technologies is expected to rise. Manufacturers that fail to adopt such ribbon technologies might see a decrease in market share in the future.

c. Furthermore, several domestic module manufacturers such as Waaree Energies, Vikram Solar, Gautam Solar, Saatvik Solar, and Bluebird Solar are opting for multi-busbar (MBB) ribbon technology, as the design minimises shading losses and improves optical gains, resulting in higher module efficiencies (Waaree Energies n.d.; Vikram Solar n.d.; Gautam Solar n.d.; Saatvik Green Energy n.d.; Bluebird Solar n.d.). Currently, MBB ribbons are offered by only a select few manufacturers, including Dhash PV,[35] Sumati Electronics, Valeo Products, and Vidya Wires (Vidya Wires n.d.; Sumati Electronics n.d.b; Valeo n.d.). Other ribbon manufacturers that fail to offer such advanced variants might see reduced demand for their products in the future, both domestically and internationally.

2. **Financial risks**: Market volatility can cause fluctuations in raw material prices, including that of copper – which moved from USD 8,351/tonne in January 2024 to USD 12,987/tonne in January 2026, an increase of 55 per cent (IEA 2026). These price fluctuations can pose a significant risk to PV ribbon manufacturers, as even slight price changes can severely impact their profit margins and undermine their competitive positioning in the market.

3. **Regulatory risks**: Copper PV ribbons are typically classified under HS headings 7407 (rods) and 7408 (copper wire), but there are no dedicated six- or eight-digit HS codes specific to solar PV applications. While some trade descriptions may reference photovoltaic ribbons, the formal tariff structure does not distinguish them based on end use. Therefore, customs duties or exemptions cannot be directly linked to solar PV usage. This creates a regulatory risk similar to the one observed for solar glass and frame manufacturers, putting compliant ribbon manufacturers at a competitive disadvantage compared to importers that are able to evade duties and avoid applicable tariffs for their imports.

> Lagging ribbon technologies, volatile copper prices, and the absence of a dedicated HS code threaten domestic PV ribbon manufacturers.

34. As per stakeholder consultation.

35. As per stakeholder consultation.

Recommendations

1. **Manufacturers should expand production to newer PV ribbon technologies to remain globally relevant**. Ribbon manufacturers should expand their portfolios to include newer technologies such as reflective ribbons, MBB and zero-busbar (0BB) ribbons, which are used to increase module efficiencies, and low-temperature ribbons, which are used in HJT and perovskite production. Further, manufacturers should aim to remove lead, a toxic metal, from PV ribbon coatings and offer lead-free products to buyers. The removal of lead can make their ribbons compliant with the *Restriction of Hazardous Substances* (RoHS) *Directive*, a vital step to prevent immediate exclusion from global markets that strictly enforce environmental standards, such as the European Union. With an increasing trend towards producing environmentally safe modules in line with international standards, ribbon manufacturers should leverage this opportunity and manufacture lead-free ribbons.
2. **Manufacturers should diversify raw material supply chains to reduce exposure to market volatility**. Ribbon manufacturers should ensure a consistent supply of raw materials through reliable inventory planning, maintaining supplier relationships, and tracking technological changes and market developments. Further, they should procure high-grade OFC or ETP from their suppliers. Another way for ribbon manufacturers to achieve this is through backward integration, i.e. setting up production facilities for high-grade copper.
3. **The CBIC should introduce a specific HS code for PV ribbons to enhance regulatory oversight, eliminate tariff misclassification, and safeguard the interests of local manufacturers before the Union Budget 2027–28**. Similar to the approach proposed for solar glass and aluminium frames, the CBIC should coordinate with the DGFT and DGTR to establish and enforce a dedicated HS code for PV ribbons. Accordingly, the industry has requested the specific HS code 74082920 for flat or round PV ribbons.[36]



Image: Dhash PV Technologies

Ribbon manufacturers provide module manufacturers with detailed instructions on winding, tension, and handling for wound spools to prevent tangling and twisting during tabbing and stringing processes.

36. As per stakeholder consultation.

5. Solar encapsulants

Solar encapsulants are polymeric sheets that enclose or encapsulate solar cells. They provide electrical insulation for solar modules, create airtight seals to block moisture ingress, and safeguard modules from potential-induced degradation (PID) (Taiyang News 2025). Solar encapsulants also contribute to the structural integrity of a solar module by bonding cells to the front glass, rear backsheet or rear glass, and metal interconnection parts such as busbars, thereby preventing delamination.

Market scenario

India's leading encapsulant manufacturers include RenewSys India (10 GW), Vishakha Renewables (6 GW), Sheetsol (6 GW), Solar Speciality Films (6 GW), Filmtec (4 GW), Alishan Green Energy (4 GW), Knack Energy (3 GW), Sunlink Photovoltaic (2 GW), Enerlite Solar Films (2 GW), Enrich (2 GW), Navitas Alpha Renewables (1.5 GW), Sunbez (1 GW), Terasol (1 GW), and Pixon Green Energy (1 GW)[37] (Figure 9). Their combined manufacturing capacity is 49.5 GW per year. Additionally, manufacturers such as Saatvik Solar, Reliance, and Tata Power Solar are planning to enter encapsulant production, while existing players have also announced expansions. By March 2028, the cumulative production capacity is expected to reach 122.5 GW per year. Accordingly, the cumulative manufacturing capacity is expected to be sufficient to meet the country's annual module demand of approximately 67 GW.
As of September 2026, domestic solar encapsulant manufacturing market was valued at approximately USD 0.51 billion.

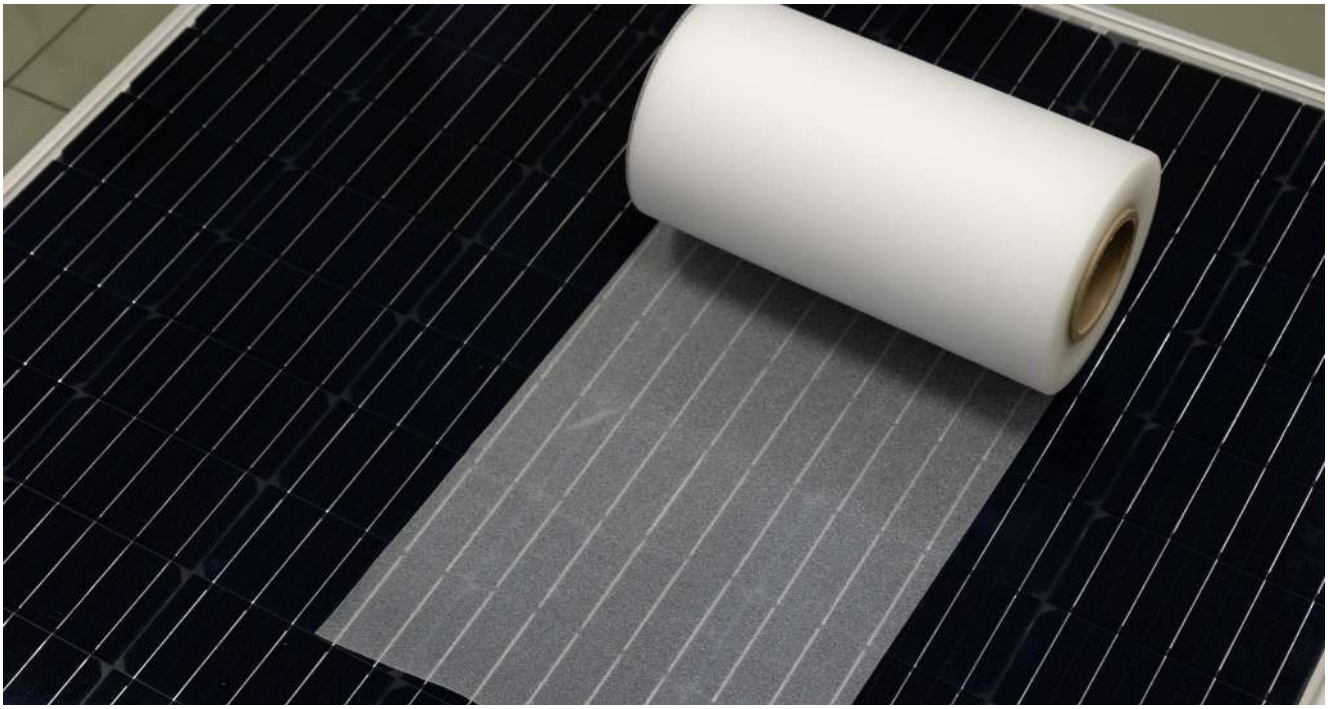
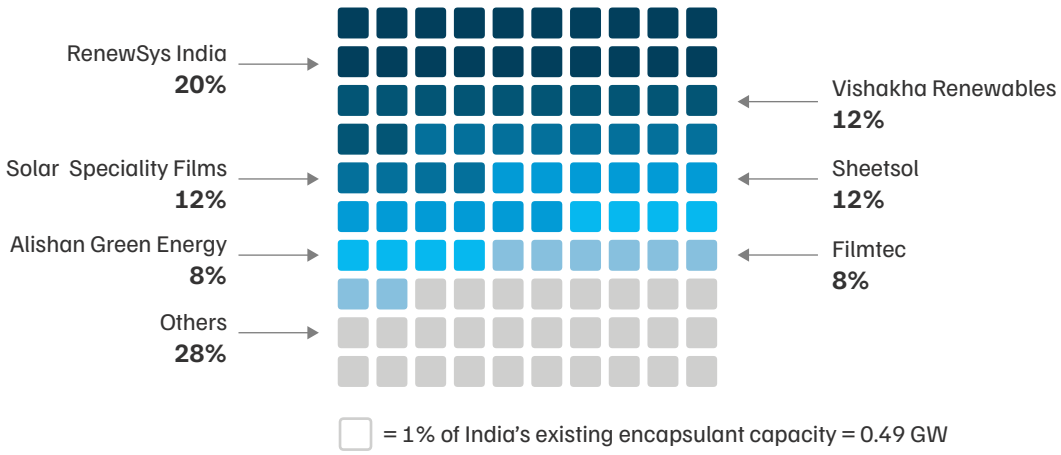


Image: RenewSys India

Solar encapsulants are made from different materials including ethylene vinyl acetate (EVA), polyolefin elastomer (POE), EVA–POE–EVA (EPE), and thermoplastic polyolefin (TPO).

37. As per September 2026 data from SAMA.

Figure 9. RenewSys India and Vishakha Renewables make up nearly one-third of the country's encapsulant manufacturing capacity



Source: Authors' compilation based on September 2026 data from Solar Ancillary Manufacturers' Association (SAMA).

Note: The percentages shown in the figure have been rounded to the nearest integer, bringing the total sum to exactly 100 per cent.

Raw materials for production of encapsulants

Ethylene vinyl acetate (EVA) and polyolefin elastomer (POE) are the two primary polymers used to manufacture encapsulants, with each offering unique advantages and limitations. To date, EVA has been the mainstream encapsulation material due to its excellent adhesive properties and high optical transparency, with a global market share of 51 per cent in FY2024–25 (Taiyang News 2025). However, under high-temperature and high-humidity conditions, EVA encapsulants can degrade, forming acetic acid, which can lead to delamination and potentially reduce module lifespan. Additionally, EVA may undergo yellowing over time under UV exposure, negatively impacting the power output of the solar module.

In contrast, POE is a non-polar material, making it resistant to degradation while also offering superior resistance to moisture ingress. Unlike EVA, POE offers superior moisture barrier, prevents acetic acid formation, relatively higher light transmission and long-term durability (Heaven Green Energy 2026). This has made POE suitable for high-powered bifacial modules; it had a global market share of 11 per cent in FY2024–25 (Taiyang News 2025). However, POE-based encapsulants have longer processing times and face challenges in lamination adhesion due to slippage, potentially contributing to busbar displacement (Taiyang News 2025). Furthermore, POE resins were priced at approximately USD 2.3 per kg globally as of December 2025 (ChemAnalyst 2025a), 28 per cent higher than EVA resins, which cost nearly USD 1.8 per kg globally during the same period (ChemAnalyst 2025b). This increases the cost of the encapsulants themselves (Shanghai Metals Market 2026b). Further, the production of POE encapsulants is more complex than that of EVA due to narrower temperature windows for lamination during manufacturing.

To utilise the advantages of both EVA and POE, another type of encapsulant, EVA–POE–EVA (EPE), is available in the market, comprising a POE layer sandwiched between two EVA layers. Compared with POE, EPE is cost-effective and offers better processability. It also offers higher moisture resistance and better anti-PID performance than EVA, but lower than POE. Thus, EPE is suited to bifacial module production optimised for both cost and performance and had a global market share of 38 per cent in FY2024–25 (Taiyang News 2025).

Other non-EVA encapsulant polymers also exist, such as thermoplastic polyolefin (TPO), which have advantages over EVA, including lower discolouration tendencies and better optical and thermal properties. In addition, they offer lower-temperature processing, making them

suitable for alternative technologies such as thin-film and tandem-perovskite technologies. However, they are not mainstream products for current module technologies globally, as they have significantly higher water permeability, which can lead to module degradation and shorter lifetimes (Dr. Hans Werner Chemikalien 2023). They had a global market share of less than 0.5 per cent in FY2024–25 (Taiyang News 2025).

In addition to polymer resins, domestic encapsulant manufacturers require additives such as UV absorbers and cross-linking agents. These are necessary for the adhesion of the encapsulant to the module when it is cured at high temperatures. According to stakeholder consultations, domestic manufacturers remain import-dependent and source both polymer resins and additives, with the polymer resin supply chain concentrated in East and Southeast Asia. However, domestic capabilities to manufacture EVA resins exist in the Indian oil and gas sector, as presented in Table 2.

Manufacturing process of solar encapsulants

Encapsulant manufacturing begins with melting solar-grade EVA or POE polymer resins at high temperatures in an extruder, along with additives such as cross-linking agents, including organic peroxide compounds (Wallner et al. 2022), UV absorbers, and coupling agents to enhance performance and stability.

The molten polymer is forced through a T-die to form thin, uniform sheets or films of the desired thickness, which are then cooled and wound into rolls. For EPE sheets, a co-extrusion process is used to produce an EVA–POE–EVA sandwich structure, offering improved processability compared to pure POE, which is prone to lamination challenges (GWELL n.d.; Taiyang News 2025). The materials required for domestic encapsulant manufacturing are highlighted in Table 2.



Image: RenewSys India

EVA encapsulants are cost-effective and transparent but moisture-permeable, prone to yellowing and acetic acid release that corrodes cell metallisation.

Table 2. While EVA and POE resins are imported by domestic manufacturers, domestic players in the oil and gas sector have the capability to diversify into EVA resin production

Raw material	Source	Domestic availability
EVA/POE resin	Global suppliers from the USA, South Korea, Japan, Taiwan, and Southeast Asia	EVA resin was previously produced domestically, but was not solar grade
Additives (cross-linking, UV absorbers, coupling agents)	Global chemical suppliers	Partially available
Naphtha (for upstream polymer production)	Domestic (Reliance, IOCL, GAIL)	Yes

Source: Authors' compilation from stakeholder consultations, SpecialChem 2022, IOCL 2026, and Creative Ecotech Group n.d.

Trade, trade-related, and non-trade barriers

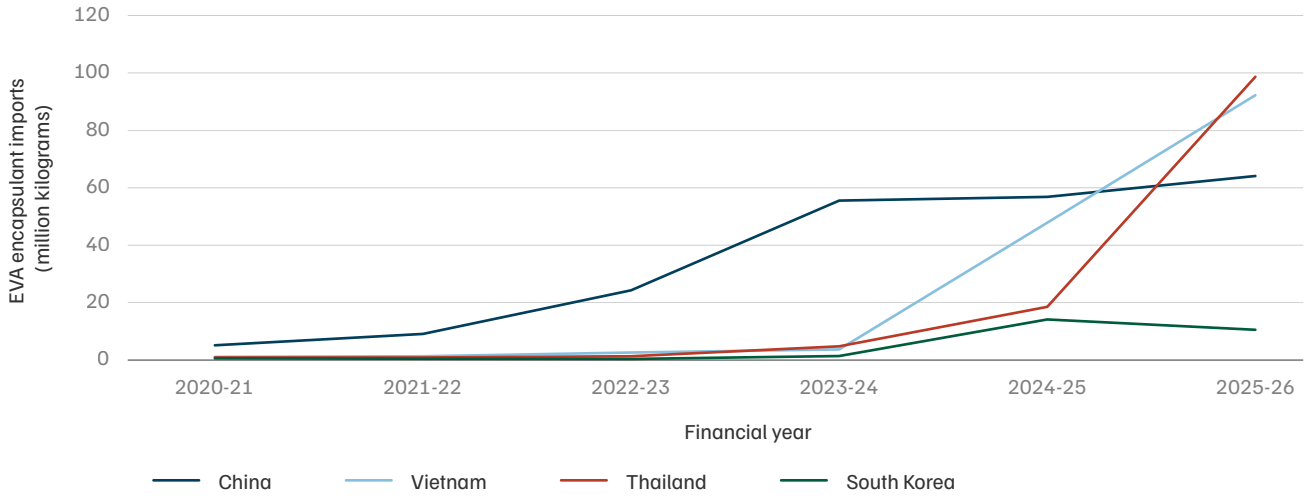
India sources its EVA sheet imports largely from China, Vietnam, Thailand, and South Korea (Figure 10). These EVA sheets, classified under Chapter 39, "Plastics and articles thereof", of the HS code for international trade, are imported under multiple HS codes: 390130, 392010, 392062, 392099, and 392190 (MoCI 2019). Despite the levy of ADD, imports have not disappeared entirely. Instead, sourcing has shifted towards alternative suppliers and higher-grade materials, resulting in trade diversion rather than full substitution. As module manufacturing capacity expands in India, imports of encapsulants have also increased, while ADD has stabilised prices for domestic manufacturers to achieve economies of scale.

Anti-dumping duty

The anti-dumping investigation concerning imports of EVA sheets for solar modules from China, Malaysia, Saudi Arabia, and Thailand was initiated in April 2018 following a petition by RenewSys India Pvt Ltd, which represented a major proportion of domestic production (MoCI 2023b). The DGTR examined normal value, export price, and dumping margins for each cooperating exporter, treating China under the non-market economy methodology where appropriate and constructing normal value based on the best available facts where cooperation was limited. The authority found that dumped imports entered India at prices significantly below fair value, resulting in price undercutting, price suppression, and financial injury to the domestic industry, including reduced profitability and adverse impacts on returns.

The DGTR recommended an ADD for five years from 2019 to 2024, which was further extended for five years until 2029 (MoCI 2024b). The final duties range from USD 537/MT to USD 590/MT for identified producers from China and USD 897/MT for all other Chinese exporters. Duties were also imposed at USD 1,338/MT for Saudi Specialised Products Company (and USD 1,559/MT for other Saudi exporters), USD 1,141/MT for TPI All Seasons (Thailand) (and USD 1,529/MT for other Thai exporters), and USD 953/MT for all Malaysian producers/exporters under the original 2019 measure; these lapsed in 2024 and were not continued. India also initiated ADD investigations into imports from South Korea, Thailand, and Vietnam in September 2025 (MoCI 2026e). The investigation is underway.

Figure 10. Thailand and Vietnam have outpaced China in the last financial year for EVA imports



Source: System on India's Export Import (Data Bank – TradeStat), MoCI (2026a). Detailed information is provided in Annexure 3, Table A8.

Note: Trade data presented in the figure are based on imports under only one HS code, 39201099, under which EVA encapsulants are mainly imported. EVA encapsulants are also imported under other HS codes. Additionally, the trade data are representative and include imports of other items such as plates, sheets, films, foils, and strips made of polymers of ethylene.

Key risks identified for Indian manufacturers

1. **Technological risks**: While the domestic industry has made progress in industrial research and development (R&D) for encapsulant sheet production, there remains limited R&D and a lack of pilot-scale solar-grade resin polymerisation infrastructure.[38] This gap constrains domestic advancements in EVA and POE film technologies. Such a lag in capabilities could create barriers for domestic manufacturers in developing innovative encapsulant variants and hinder their ability to emerge as global suppliers of advanced products.

2. **Quality assurance risks**: Domestic manufacturers exhibit non-uniform quality control practices. For RenewSys India (RenewSys 2025a), Alishan Green Energy (Alishan Green Energy 2025a), and Vishakha Renewables (Vishakha Renewables 2025a), it was found that the testing standards and protocols used for a few important parameters, such as electrical insulation and water absorption, differ. Among these three, Vishakha Renewables and RenewSys India explicitly specify electrical insulation tests on their datasheets (e.g. dielectric strength and volume resistivity, with Vishakha Renewables additionally listing the Comparative Tracking Index (CTI) per IEC 60112), whereas Alishan Green Energy does not specify any electrical tests, even though it details mechanical, optical, and curing properties. These discrepancies provide an incomplete picture of the overall quality control practices followed by domestic manufacturers.[39] Further, a lack of electrical testing makes encapsulants unreliable for protection against PID. These inconsistencies in quality control can undermine buyers' confidence in local encapsulants.

3. **Supply chain risks**:[40] Indian encapsulant manufacturers are dependent on imported EVA and POE resins from South Korea, Japan, and Southeast Asia, creating supply chain vulnerabilities. Nearly 54 per cent[41] of EVA resin imported in FY2026 was from South Korea (MoCI 2026a). This resulting import dependence exposes domestic encapsulant manufacturers to currency volatility and freight cost fluctuations (Taiyang News 2025).

4. **Regulatory risks**: Similar to the components discussed previously, EVA is imported under multiple HS classifications, which creates serious enforcement and policy challenges and puts compliant domestic manufacturers at a competitive disadvantage.

Recommendations

1. **Manufacturers, the MNRE, and the BIS should standardise quality control across all domestic manufacturers to ensure consistent product performance and reliability**. These stakeholders should work in consortia to develop uniform testing standards and guidelines which are currently insufficient, creating consistency among manufacturers. This will ensure that encapsulants from all domestic manufacturers follow the same set of standards for quality checks, improving buyer confidence.

2. **Manufacturers should strengthen collaboration with domestic resin manufacturers to enhance supply chain resilience, with support from the MNRE and the MoPNG for pilot establishment**. They should collaborate to design pilot-scale lines to indigenise EVA resin manufacturing, which should be funded through inter-ministerial collaboration between the MNRE and the Ministry of Petroleum and Natural Gas (MoPNG). Petrochemical companies such as Reliance Industries, IOCL, and GAIL would be ideal complementary industries to enter this value chain. Reliance Industries historically produced non-solar-grade EVA resin with a vinyl acetate (VA) content of 18 per cent, lower than the 26–28 per cent VA content required for solar-grade EVA resin (SpecialChem 2022). Changing the VA content during EVA production does not require changes to the overall industrial process, as it can be carried out in a standardised high-pressure autoclave reactor.

> Dependence on imported resins, inconsistent quality testing, and limited R&D leave domestic encapsulant manufacturers vulnerable.

38. As per stakeholder consultation.
39. The authors note that company datasheets are not comprehensive quality records and may contain inconsistencies in data disclosure.
40. Supply chain risk refers to vulnerabilities within a global network that can delay or halt a manufacturer's production by interrupting the flow of raw materials.
41. In FY2026, EVA resin imports from South Korea equalled 178.91 million kilograms from India's total EVA resin imports of 328.69 million kilograms.

However, it requires optimisation of operating variables such as autoclave pressure, the temperature setpoints of the three-zone temperature loop, fresh ethylene feed rate, comonomer fresh feed rate, and chain modifier feed rate (Chien et al. 2007). Hence, a potential shift in EVA quality from non-solar grade to solar grade appears technologically feasible. Some petrochemical companies such as IOCL and GAIL are already involved in the production of polymers such as high-density polyethylene (HDPE) and linear low-density polyethylene (LLDPE) (IOCL 2026; Creative Ecotech Group n.d.). Naphtha is already used by IOCL to produce precursor polymers, essential in the production of EVA resin. Such technical expertise in large-scale polymer production can be leveraged to manufacture solar-grade EVA.

3. **The CBIC should introduce specific HS codes for different variants of encapsulants to strengthen customs enforcement and safeguard the interests of local manufacturers before the Union Budget 2027–28**. It should coordinate with the DGFT and DGTR to introduce dedicated eight-digit HS codes for different encapsulant variants based on their base material and application. This will help the authorities track import volumes and strengthen the implementation of trade remedies.



Image: Vishakha Renewables

Inappropriate storage conditions for encapsulants lead to material degradation, moisture absorption, and physical deformation.

6. Solar backsheets

Solar backsheets are multilayer protective composites laminated to the rear side of a solar module. Their primary functions are to provide electrical insulation and mechanical strength. In addition, backsheets protect modules against harmful environmental influences such as ultraviolet (UV) radiation, moisture, extreme temperatures, and microparticles such as sand grains (Taiyang News 2025).

Backsheets are composed of a three-layer polymer structure: an inner layer adjacent to the solar cells, a core layer, and an outer layer exposed to the atmosphere. Based on their constituent materials, backsheets can be classified as fluoropolymer-based or non-fluoropolymer-based. A fluoropolymer-based backsheet features a polyethylene terephthalate (PET) core layer, which provides environmental protection, electrical insulation, and long-term durability, sandwiched between two fluoropolymer layers such as polyvinyl fluoride (PVF) or polyvinylidene fluoride (PVDF) (Taiyang News 2025).

These fluoropolymer layers provide UV protection, as PET has poor UV stability. Variants of fluoropolymer backsheets also exist with a single fluoropolymer layer, an inner layer of EVA-blended polyolefin (POE), and a PET core layer. This configuration balances costs while still providing UV protection, as the inner, cell-adjacent layer receives negligible UV radiation compared to the outer layer. In non-fluoropolymer backsheets, the outer fluoropolymer layer is replaced with a hydrolysed PET layer, a surface-modified PET film (Vishakha Renewables 2025b). Such hydrolysed PET films offer greater resistance to moisture, UV radiation, and degradation due to treatment with hydrolysis inhibitors (HyMax 2023). Apart from the three-layer structure, twin- and monolayer configurations have also emerged. Such backsheets involve the replacement of a fluoropolymer layer with a coated film (Novanext 2025). Variants that replace both fluoropolymer layers with coatings are termed coating–PET–coating (CPC).



Image: Vishakha Renewables

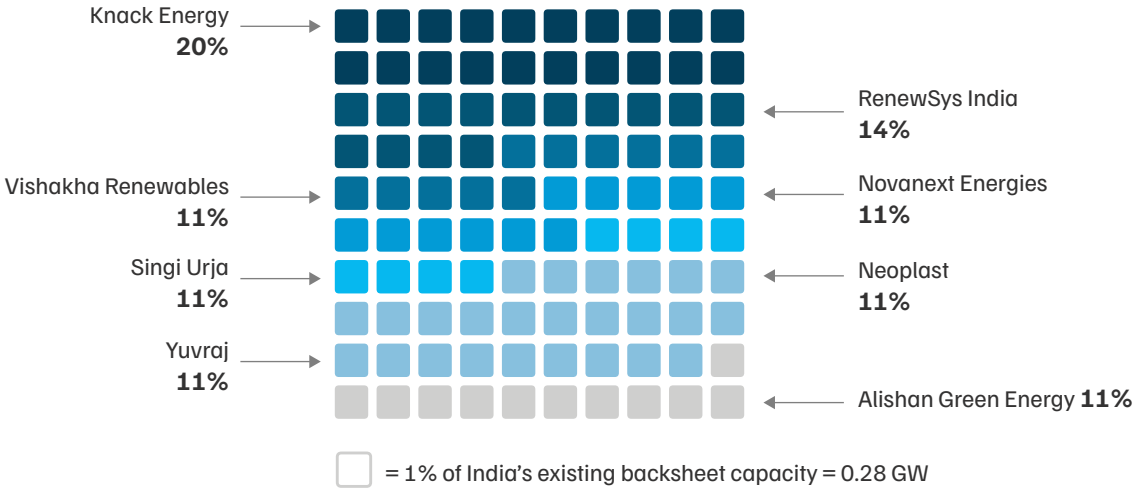
The primary defect of a backsheet is its tendency to crack and delaminate under intense UV exposure and thermal stress, allowing moisture ingress that causes catastrophic module failure.

Market scenario

As of September 2026, domestic backsheet manufacturers include Knack Energy (6 GW), RenewSys India (4 GW), Vishakha Renewables (3 GW), Novanext Energies (3 GW), Singi Urja (3 GW), Neoplast (3 GW), Yuvraj (3 GW), and Alishan Green Energy (3 GW), bringing the cumulative capacity to 28 GW per year (Figure 11). These manufacturers have either limited or completely stopped production, with no planned capacity expansions[42]. This shift is primarily driven by the increasing adoption of glass–glass modules, which has significantly reduced demand for backsheets, rendering the market for conventional backsheets largely obsolete.

Domestic backsheet producers currently offer both non-fluoropolymer and fluoropolymer products. However, only three of the five domestic producers presented in Table 3 offer CPC backsheets.

Figure 11. All backsheet manufacturers have similar production capacities except Knack Energy and RenewSys India



Source: Authors' compilation based on September 2026 data from Solar Ancillary Manufacturers' Association (SAMA).

Note: The percentages shown in the figure have been rounded to the nearest integer, bringing the total sum to exactly 100 per cent. For Knack Energy, the figure has been rounded to the nearest ten.

Table 3. Domestic backsheet manufacturers offer products across all categories

Manufacturer	Non-fluoropolymer backsheets	Fluoropolymer backsheets	Coating based backsheets
Knack Energy	✓	✓	✓
Vishakha Renewables	✓	✓	
RenewSys India	✓	✓	
Novanext	✓	✓	✓
Alishan Green Energy	✓	✓	✓

Source: Knack Energy (2026), Vishakha Renewables (2026), RenewSys (2026), Novanext (2025), and Alishan Green Energy (2025b).

Note: This is a representative selection of manufacturers by product type and is not exhaustive.

42. As per stakeholder consultations.

Globally, CPC backsheets have become the dominant configuration, with a market share of 60 per cent[43] in 2024 (Taiyang News 2025). The shift towards CPC backsheets has been driven by their cost-effectiveness. At the end of 2023, the cost difference between PVDF and CPC backsheets was nearly renminbi (RMB) 1.8–2 per square metre (Taiyang News 2025). In China, CPC backsheets have also become popular, accounting for more than half the sales of major Chinese backsheet suppliers such as Jolywood, Cybrid, and First PV Material, indicating their growing prominence (PV Magazine 2025). However, domestic module manufacturers have been hesitant to adopt CPC backsheets due to their higher water vapour transmission rate (WVTR).[44] The WVTR of these products is higher than 2 g/m^2/day, compared with 1.2–1.4 g/m^2/day for conventional three-layer laminate backsheets.[45]

Manufacturing process of solar backsheets

Raw material preparation begins with drying polymer pellets, such as PET, PVF, or PVDF, to remove moisture, which is crucial to prevent degradation during the melting process. Domestic manufacturers import these pellets or resins mainly from China (MoCI 2026a). Drying is carried out using desiccant or vacuum dryers (Shini USA n.d.; Maguire 2020). Next, the dried pellets are melted in an extruder. An extruder is a long barrel with a rotating screw inside. As the pellets travel along the barrel, they pass through progressively hotter zones where they melt. The screw then pushes the molten plastic towards a die. The molten polymer exits the extruder through a flat die, which spreads it into a wide, thin sheet of uniform thickness. This molten film lands on a cooled metal roller, where it solidifies, helping to establish the film's crystalline structure and dimensional stability.

The film's thickness is regulated through die-gap adjustments, tension control on rollers, and precision calendaring. Optionally, biaxial orientation, which involves stretching in both the machine and transverse directions, is applied to PET films to enhance their strength, barrier properties, and dimensional stability. The film then undergoes surface treatment, if required. This includes corona discharge or plasma treatment, which increases surface energy and improves adhesion to adhesives or other layers. This is particularly important for the core PET film, which bonds to the adhesive and outer layers. Finally, the finished film is wound into large rolls under controlled tension. These films are then laminated together using adhesives such as polyurethane, epoxy silane, or EVA-based adhesives. However, this step is carried out only for fluoropolymer- and non-fluoropolymer-based backsheets. For coating-based backsheets, the final step in the production process consists of depositing a coating layer on the PET core.

Finally, post-production quality checks are conducted before packaging. These include testing parameters such as tensile strength (ASTM D 882), elongation at break (ASTM D 882), thermal shrinkage (ASTM D 1204), adhesion strength with the encapsulant and between layers (ASTM D 903), water vapour transmission rate (ASTM F 1249), and electrical insulation properties such as system voltage (IEC 61730-1) and comparative tracking index (IEC 60112) (RenewSys 2025b).

Trade, trade-related, and non-trade barriers

Backsheets are commonly imported from East and Southeast Asian producers, including China, Taiwan, and Thailand, as shown in Figure 12. Most imports take place under HS codes 3920 and 3921; however, imports may also take place under other HS codes.

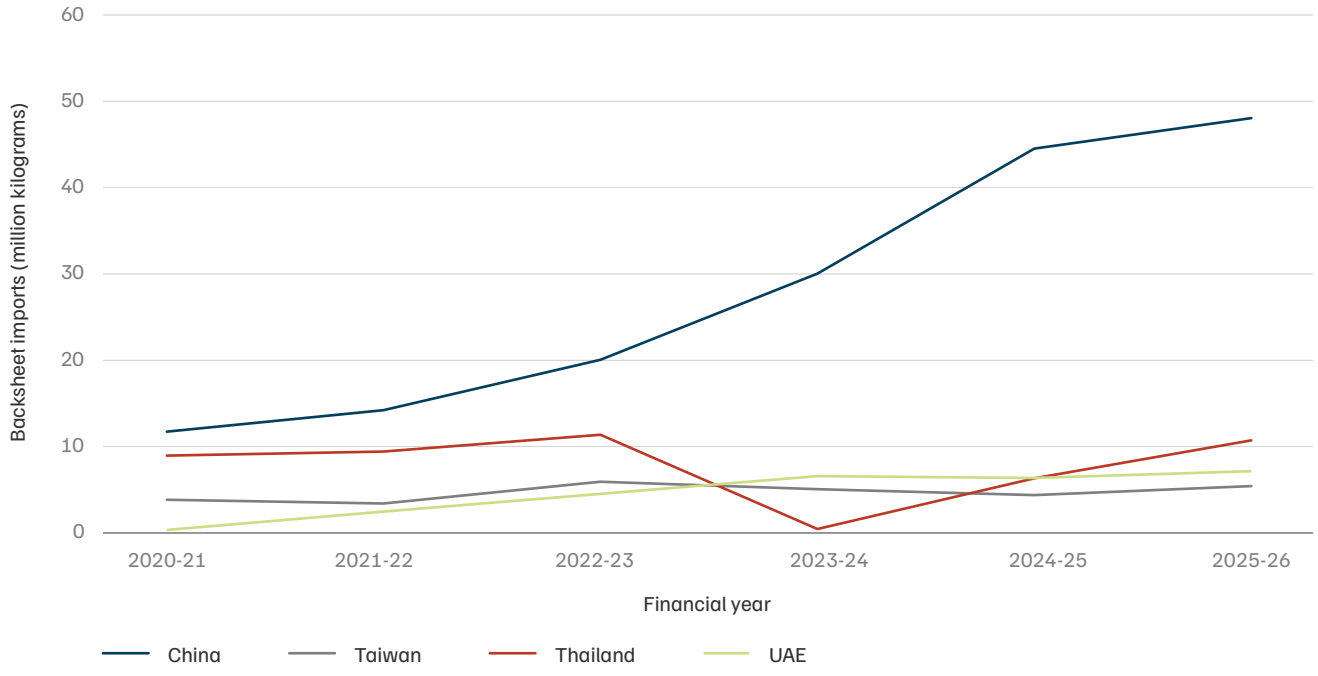
43. Market share of other backsheet variants in 2024: non-fluoropolymer – 30%, PVDF – 7%, and PVF – 3% (Taiyang News 2025).
44. WVTR measures how fast moisture passes through a material to sensitive components inside the module.
45. As per stakeholder consultation.



Image: RenewSys India

Backsheet production has declined due to the increased adoption of glass-glass modules in new age technologies such as TOPCon.

Figure 12. China is a major exporter of solar backsheets to India



Source: System on India's Export Import (Data Bank – TradeStat), MoCI (2026a). Detailed information is provided in Annexure 3, Table A9.

Note: Trade data presented in the figure are based on imports under only one HS code, 39206290, as backsheets are mainly imported under this specific HS code. Backsheets are also imported under other HS codes. Additionally, these trade data are representative and include imports of other items such as plates, sheets, films, foils, and strips made of polyethylene terephthalate (PET).

Anti-dumping duty investigations

An anti-dumping investigation concerning imports of fluoropolymer backsheets from China was initiated by the DGTR following a petition filed by RenewSys India Pvt Ltd, the major domestic producer (MoCI 2022). The investigation examined the period from 1 October 2019 to 30 September 2020. The DGTR found that imports of fluoropolymer backsheets from China were dumped in the Indian market and had increased significantly, leading to price undercutting and suppression of domestic prices, which prevented the domestic industry from recovering costs and earning reasonable returns. The domestic industry was found to have suffered material injury, reflected in deteriorating profitability, reduced returns on capital employed, and an adverse impact on production performance despite growing demand in the solar PV sector. In its final findings dated 29 March 2022, the DGTR recommended a duty of USD 762/MT for Jolywood (Suzhou) Sunwatt Co Ltd and USD 908/MT for any other company in China or outside China. The MoF imposed the duty in June 2022 (MoF 2022). The duty is valid until June 2027.

The ADD on fluoropolymer backsheets has been effective in correcting price undercutting by Chinese imports, enabling domestic manufacturers to stabilise prices and improve profitability. The levy of ADD is significant here, as the majority of imports are from China, supporting the recovery of domestic capacity.

Key risks identified for Indian manufacturers

1. **Technological risks**:

a. The Indian solar module market has seen a rise in bifacial glass–glass modules, as reflected in their increasing share in quarterly ALMM List-I updates. The share of bifacial glass–glass modules in these updates rose from 75 per cent in December 2025 to 96 per cent in March 2026, as shown in Annexure 2.[46] This mirrors the growing popularity of bifacial glass–glass modules globally (Taiyang News 2025). Such modules do not require backsheets, creating a risk of market obsolescence for conventional backsheets (VDMA 2025).

b. Domestic backsheet manufacturers such as Vishakha Renewables produce backsheets with a thickness of 370 micrometres (Vishakha Renewables 2025b), compared with Chinese manufacturers such as Jolywood that produce backsheets ranging from 250 to 325 micrometres (Jolywood 2025). While thicker backsheets offer better electrical insulation, higher mechanical support, and higher moisture resistance, they increase material consumption for backsheet production by 29 per cent per module, measured by volume.[47] An inability to match thinner imported backsheets while providing similar protection can increase costs due to higher material consumption.

2. **Supply chain risks**: Domestic manufacturers are largely dependent on Chinese imports for polymer resins (PET, PVF, and PVDF) used in backsheet production[48]. This dependence creates vulnerability to supply chain disruptions, which could affect the ability of domestic manufacturers to produce backsheets.

3. **Regulatory risks**:

a. In March 2022, the DGTR recommended an ADD on imports of solar backsheets to bridge the cost gap between Chinese imports and domestically produced backsheets (MoCI 2022). However, it is limited to fluoropolymer-based backsheets and excludes transparent backsheets. This leaves domestic manufacturers producing non-fluoropolymer- and coating-based backsheets at a competitive disadvantage.

b. Backsheets are also imported under HS chapter classifications 3920 and 3921, similar to the BOM components discussed previously. The lack of product-specific classifications can create regulatory challenges for the government. This practice enables duty evasion and regulatory arbitrage, allowing importers to avoid applicable tariffs, quality controls, or safeguard measures while placing compliant domestic manufacturers at a competitive disadvantage. Recent cases also show that differences between how goods are classified (by material) and how exemptions are granted (by end use) add to the problem, leading to misclassification of inputs, inconsistent exemptions, and subsequent duty demands (Office of the Principal Commissioner of Customs 2023).

46. Quarterly updates are more reflective of current industry trends than the entire ALMM List-I which will have legacy lines using old technologies; hence, change in quarterly updates is showcased.

47. Percentage increase in volume = percentage increase in thickness (as area is constant) = (370 – 287.5)*100/287.5 = ~29%. 287.5 µm is the average thickness assumed for Chinese backsheets.

48. As per stakeholder consultations.

Recommendations

1. **Manufacturers should explore expanding their product portfolios to maintain market relevance**. The biggest risk for backsheet manufacturers is market obsolescence. They should focus on producing transparent backsheets to retain demand from bifacial module manufacturers. Transparent backsheets are made of clarified PET material with high optical transmittance, allowing incident light to reach the rear side of bifacial modules (Kwon et al. 2025). Such backsheets do not require changes to the manufacturing process but require higher quality control to ensure transparency. Transparent backsheets can also offer advantages to module manufacturers when used as a rear-side covering instead of glass, including superior heat dissipation and fewer limitations on the stacking and storage of modules due to their lower weight (Taiyang News 2025). Their lighter weight makes these modules particularly beneficial for rooftop applications, where structural load capacity may be a constraint. Conversely, modules using transparent backsheets have a higher WVTR than glass–glass modules, which may lead to higher annual module degradation after the first few years of installation.[49] Increased R&D is therefore required to improve their intrinsic characteristics.

> Bifacial modules with transparent backsheets on the rear side are lighter, providing a clear advantage for rooftop applications.

2. **Manufacturers should strengthen collaboration with local resin suppliers to develop a resilient raw material supply chain**. They should consider sourcing PVF and PVDF polymer resins from domestic suppliers such as Gujarat Fluorochemicals Ltd (GFL) to further indigenise the value chain and strengthen its resilience (GFL 2018)[50]. Backsheet manufacturers should ensure that the mechanical properties of local resins such as tensile break strength, elongation, and interlayer adhesion are comparable to those of PVDF resins manufactured by international suppliers such as Arkema, which is widely used in solar backsheet production (Arkema n.d.).

3. **The DGTR should investigate the dumping and injury caused to all other backsheet segments**. These include transparent non-fluoropolymer-based, and coating-based backsheets. Import duties should be levied if injury to local manufacturers is determined. Such policy measures would provide support to the declining domestic backsheet manufacturing industry.

4. **The CBIC, along with the DGFT and DGTR, should introduce specific HS codes for different backsheet variants to strengthen customs enforcement and safeguard the interests of local manufacturers before the Union Budget 2027–28**. An approach similar to that proposed for encapsulants should be considered for backsheets.

49. As per stakeholder consultation.

50. As per stakeholder consultation, the company has capabilities to produce PVF and PVDF polymer resins in pellet form for multiple end applications, including solar.

7. Solar junction boxes

A solar junction box is a sealed enclosure mounted on the back of a solar module. It houses cable terminations and bypass diodes and serves as the central interface for electrical connections. The junction box ensures safe current flow, provides strain relief for cables, and protects components against dust, moisture, and UV radiation in accordance with international standards IEC 62790/UL[51] 3730/IS 16911 at the product level and IEC 61215 at the module level.

Solar junction boxes contain potting materials that make them resilient to damp-heat conditions, hotspots, thermal cycling, and moisture ingress. The presence of potting materials and bypass diodes, along with the fact that junction boxes collect only direct current (DC), differentiates them from conventional junction boxes. Multiple types of junction boxes are available in the market (Table 4). Current passivated emitter and rear cell (PERC) and tunnel oxide passivated contact (TOPCon) module manufacturers prefer split junction boxes. Older monofacial back surface field (BSF) modules used one of the other three types of junction boxes: potted, pre-potted, or non-potted.



Image: Dhash PV Technologies

The junction box and MC4 connectors function in tandem to form the primary electrical output infrastructure of a solar module.

51. UL - Underwriters Laboratories.

Table 4. Each variant of junction box has its own set of drawbacks

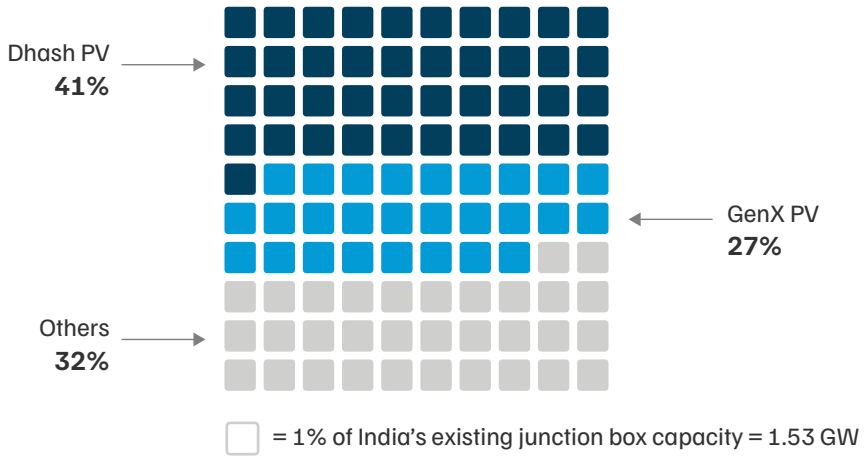
Junction box type	Description	Drawback
Split junction boxes	The junction box is divided into multiple smaller units, each containing its own bypass diodes. Bypass diodes help distribute heat evenly and improve reliability.	More complex assembly and alignment on automated lines.
Potted	Filled and sealed with epoxy or silicone resin after assembly, providing protection against moisture and thermal stress.	Renders the components non-serviceable.
Pre-potted	Comes prefilled with the potting compound by the supplier, simplifying assembly and ensuring consistent sealing once cured, making it suitable for mass manufacturing.	Less flexibility for manufacturers seeking to adjust potting parameters.
Non-potted	Uses gaskets, snap-fits, ultrasonic welding, or mechanical sealing instead of resin potting, making it lighter and less costly than other junction boxes.	Less durable under thermal cycling and offers the lowest protection against moisture ingress.

Source: Authors' compilation from Ghasemi et al. (2025), Dhash PV (2025), and TE Connectivity (n.d.).

Market scenario

As of September 2026, leading domestic junction box manufacturers include Dhash PV (63 GW), GenX PV (42 GW), Arbon Cleantech (8 GW), Helios Power (4 GW), ShankShila (4 GW), Radial Solar (4 GW), Orin2 PV (4 GW), V Mould (4 GW), Solera (4 GW), Raychem RPG (4 GW), Transfix (4 GW), Sperry (4 GW), and Sunlink Photovoltaic (4 GW), with a combined annual manufacturing capacity of 153 GW (Figure 13). Further, GenX PV is planning a 10 GW expansion, which would increase domestic junction box manufacturing capacity to 163 GW by March 2027. As such, cumulative manufacturing capacity is expected to be more than sufficient to meet domestic module demand of approximately 67 GW annually. Further, a majority of junction box manufacturers offer split junction boxes, the type currently preferred by new-age module manufacturers. As of September 2026, the domestic junction box manufacturing market was valued at approximately USD 0.44 billion.

Figure 13. Dhash PV and GenX PV contribute to nearly 70% of India's junction box manufacturing capacity



Source: Authors' compilation based on September 2026 data from Solar Ancillary Manufacturers' Association (SAMA).

Note: The percentages shown in the figure have been rounded to the nearest integer, bringing the total sum to exactly 100 per cent.

Raw materials required for junction box production

Key raw materials required for solar junction box manufacturing include engineering thermoplastics, such as polyphenylene ether (PPE)-based grades, including polyphenylene oxide (PPO), polyamide (PA), or polycarbonate (PC); tinned copper terminals; bypass diodes; silicone potting gels; silicone adhesives; and DC solar cables made from copper wires.

Standard plastics, metals, and basic electrical components, are domestically sourced. However, according to stakeholders, bypass diodes (which are semiconductors) used in junction boxes are largely imported, along with bypass diodes used for other applications. There is no specific HS code for bypass diodes used in solar junction boxes; hence, they are imported under the same HS code as bypass diodes used for other applications. Total diode imports[52] were USD 451.77 million and USD 504.79 million in FY2025 and FY2026, respectively. Of these, USD 164.87 million and USD 181.56 million were imported from China in FY2025 and FY2026, respectively, accounting for an average of 36 per cent of total imports (MoCI 2026a). While these data do not provide the exact quantity of bypass diodes imported for domestic junction box manufacturing, they indicate broader import dependence, which has been further confirmed through stakeholder consultations.

Manufacturing process of solar junction boxes

Solar junction box manufacturing involves several precise stages combining plastic moulding, electrical assembly, and testing to ensure reliability under harsh outdoor conditions (Linkwell Electric 2025; Webel Solar n.d.). Domestic manufacturers source certain raw materials from outside India but carry out the manufacturing processes domestically.

First, the housing is injection-moulded from thermoplastics such as PPO, PA, or PC. Copper busbars and bypass diodes are then assembled using soldering or press-fit technology. The PV cables are attached through precision stripping and crimping to ensure strong mechanical retention. Junction boxes are then sealed and closed to achieve IP67 and IP68[53].

Both IP67 and IP68 standards signify complete protection against dust ingress and provide water resistance (IEC 2026). However, IP67 signifies water resistance against submersion in up to one metre of water for 30 minutes (Electrical Safety Testing Laboratory 2025a), while IP68 signifies protection against prolonged water immersion beyond one metre (Electrical Safety Testing Laboratory 2025b).



Image: Dhash PV Technologies

Junction box manufacturing not only involves electrical and electronic items but also requires high-grade engineering thermoplastics as raw materials.

52. HS code for diodes considered here is 854110 – diodes other than photosensitive and light emitting diodes.

53. IP – Ingress Protection.

Electrical and mechanical testing is carried out as the final step by junction box manufacturers and includes insulation resistance and environmental durability testing. Further, once the junction box reaches the solar module manufacturer, internal components are potted using two-component room-temperature vulcanisation (RTV-2) silicone to provide insulation and heat dissipation. This process is carried out for split junction boxes, while older products, such as pre-potted junction boxes designed for older module technologies, would have potting carried out by the junction box manufacturer.

Trade, trade-related, and non-trade barriers

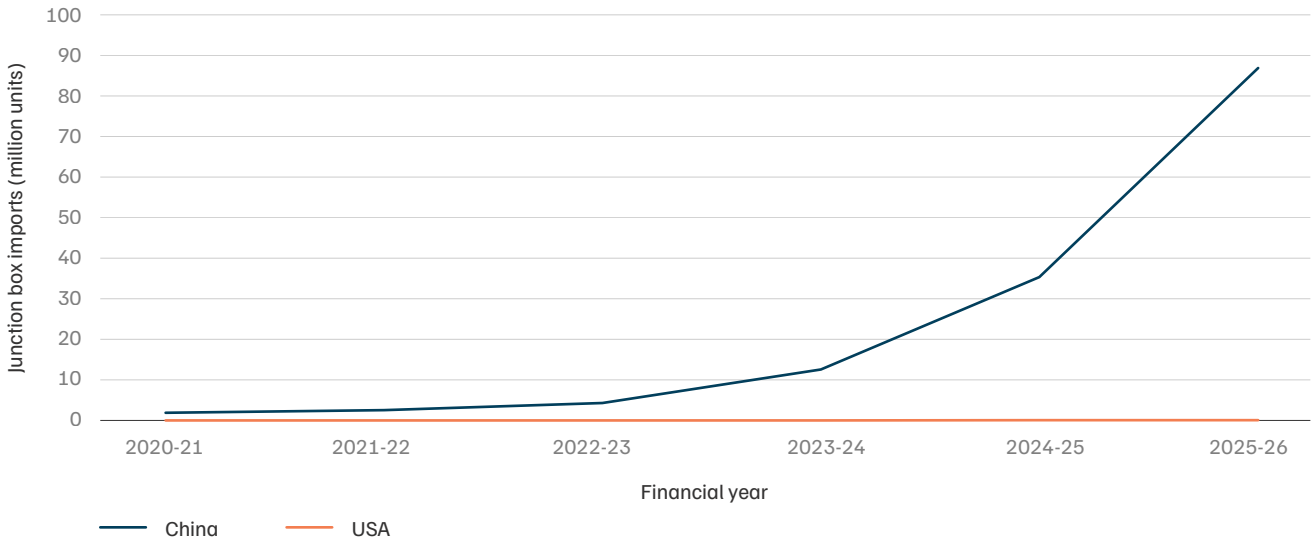
Junction boxes are largely imported from China, but domestic manufacturers have scaled rapidly following procurement preference signals and industry measures (Figure 14). No major ADDs specifically target junction boxes. At the six-digit level, junction boxes can be imported under several HS codes, with no specification of their end use (MoCI 2014).

Key risks identified for Indian manufacturers

1. **Manufacturing risks**: According to stakeholder consultations, domestic manufacturers struggle to produce robust designs that consistently adhere to solar modules. Solar module manufacturers differ in the automated processes used during assembly, and variations in the module assembly process, including changes in backsheet material, potting material, applied pressure, and curing time, can affect junction box adhesion (Electrical Safety Testing Laboratory 2025b; Volberg n.d.; DuPont n.d.; IEA-PVPS 2014).

2. **Technological risks**: Research and development in solar junction boxes indicates that even split junction box designs are prone to hotspot generation in PV modules during operation, as their attachment to the back of the PV panel can lead to local overheating and reduced cooling (Turaev et al. 2026). A potential solution is to relocate split junction boxes onto frames to address such local overheating. While such designs have not yet been commercialised globally or domestically, failure to monitor and adapt to such an emerging technology could render domestic manufacturers technologically non-competitive.

Figure 14. Almost all junction boxes are imported from China



Source: System on India's Export Import (Data Bank – TradeStat), MoCI (2026a). Detailed information is provided in Annexure 3, Table A10.

Note: Trade data presented in the figure are based on imports under only one HS code, 85359040, as junction boxes are mainly imported under this specific HS code. Additionally, these trade data are representative and include imports of other junction boxes with different end applications.

3. **Quality assurance risks**: Stakeholder consultations have revealed a lack of National Accreditation Board for Testing and Calibration Laboratories (NABL)-accredited testing laboratories for junction boxes. Further, most testing centres test junction boxes already attached to solar modules but lack specific testing of junction boxes themselves after production. Individual junction box testing is critical as it can validate its performance, durability, and electrical safety. Its absence can deter buyer confidence.

4. **Supply chain risks**: Junction box manufacturers depend on imported diode components. Diodes have long production lead times, and each diode requires a specific current rating depending on module wattage (Mercom India 2025b). The evolution of solar module technology towards higher wattage ranges has made it difficult to forecast diode demand and obtain diodes with the optimal current rating. Similarly, junction box manufacturers are also dependent on imports of thermoplastics and DC cables – requiring specific grades. Dhash PV is the only domestic manufacturer currently involved in plastic injection moulding and DC cable manufacturing through backward integration.[54]

5. **Regulatory risks**: Similar to the other components discussed, junction boxes are imported under multiple HS classifications, creating enforcement and policy challenges and putting compliant domestic manufacturers at a competitive disadvantage.

Recommendations

1. **Manufacturers should develop adaptable designs in collaboration with module manufacturers to offer products with improved reliability and performance**. Manufacturers should focus on adaptable designs and adhesive systems that remain compatible with varying module assembly conditions, including differences in backsheets, potting materials, pressure, and curing times. They should also collaborate closely with solar module manufacturers to test and optimise junction boxes for specific assembly processes. Junction box producers should further explore innovations targeting split junction boxes. For example, frame-mounted junction boxes can reduce panel temperatures uniformly by 35 per cent (Turaev et al. 2026), which could improve module performance under India's hot climatic conditions. Early adoption of these innovative designs could create a first-mover opportunity, as such junction boxes have not yet been mainstreamed.

2. **Manufacturers, the MNRE, and the BIS should work together to ensure uniform quality control practices are followed**. Quality control of junction boxes against variations in the module assembly process should also be tested. This could be achieved by incorporating partial tests that assess junction box adhesion against changes in backsheet material, potting material, applied pressure, and curing time (Volberg n.d.). NABL-accredited labs should possess component level testing capabilities basis IEC 62790. Further, third-party laboratories should also be given NABL accreditation to carry out junction box assembly testing.[55]

3. **The Ministry of Electronics and Information Technology (MeitY) and the MNRE should coordinate to strengthen domestic manufacturing of bypass diodes to secure the raw material supply chain**. This should be done by including junction box components such as bypass diodes under the selected target segments covered by the *Electronics Component Manufacturing Scheme* (ECMS) (MeitY 2026) to support indigenisation. Junction box diodes could be included under the target segment 'electro-mechanicals'. As of March 2026, 75 applications have been approved under the ECMS which has a total outlay of INR 400 billion (INR 40,000 crore) (PIB Delhi 2026). Under this scheme, manufacturing support is provided through turnover-related incentives, capital expenditure incentives, or a combination of both. Manufacturers such as Dhash PV have already begun developing infrastructure to produce solar cables and diodes (Mercom India 2024).

4. **The CBIC, along with the DGFT and DGTR, should introduce a specific HS code for junction boxes used in solar modules to strengthen customs enforcement and safeguard the interests of local manufacturers before the Union Budget 2027–28**. An approach similar to that proposed for the other components should be implemented for junction boxes. The industry has proposed HS code 85359050 for junction boxes used in solar modules.[56]

> Manufacturers are highly dependent on imports of bypass diodes, engineering thermoplastics and DC cables for junction box production.

54. As per stakeholder consultation.
55. As per stakeholder consultation.
56. As per stakeholder consultation.

Demand-side measures

While supply-side measures are necessary, a resilient and self-reliant ecosystem will also require certain demand-side measures across all components. These include:

1. **The MNRE should introduce an ALMM list for all BOM components, similar to the ALMM list for cells and modules**. ALMM acts as a non-tariff barrier and promotes domestic manufacturing by heavily restricting imports. Under ALMM, all government-backed, net-metered, and open-access solar installations in the country are mandated to source components exclusively from approved domestic manufacturers. The list should be introduced in January 2028 and made effective from January 2029. This would provide manufacturers with sufficient time to complete their expansions and optimise their manufacturing processes - avoiding any supply-chain bottlenecks for domestic module manufacturers. BOM manufacturers can also utilise this period to diversify their raw material supply-chains, strengthen their testing standards, and manufacture products at par with international standards.
2. **The MNRE should extend the *Domestic Content Requirement* (DCR) to include all BOM components** in addition to cells and modules. This should be made effective from January 2028 to promote the use of domestic BOM components in solar modules. This will provide a realistic timeline for module manufacturers to source local BOM components. Introducing DCR will enforce the use of local BOM components in government flagship schemes like *Pradhan Mantri Surya Ghar: Muft Bijli Yojana* (PM-SGMBY) and *Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyaan* (PM-KUSUM) – where failing to use a DCR-compliant module disqualifies beneficiaries, such as homeowners and farmers, from receiving the Central Financial Assistance (CFA) subsidy. Central Public Sector Undertakings (CPSUs) and government-tendered projects will also be mandated to use modules with local BOM components.



Image: Dhash PV Technologies

Uniform testing protocols followed by all domestic BOM manufacturers will ensure strict quality control and improve buyer confidence.

8. Conclusion

The study aims to support creating a resilient, self-reliant, and competitive BOM manufacturing industry not only for India but also for the global market. For this, it addresses several knowledge gaps and provides much-needed information on India's BOM manufacturing ecosystem, including the cumulative manufacturing capacities of individual BOM components, their manufacturing processes and raw material requirements, and the different models and variants produced. It also provides details on the trade barriers imposed by the government on different BOM components to protect domestic manufacturers.

Drawing on these findings, the study identifies several cross-cutting challenges across technological, manufacturing, quality assurance, supply chain, regulatory, and financial dimensions. Primary among these is the difficulty of keeping pace with the rapid technological advancements seen at a global level while simultaneously maintaining uniform testing standards for rigorous quality control. India's dependence on imported raw materials, ranging from limestone and sodium antimonate for solar glass to polymer resins for encapsulants, creates a significant vulnerability for domestic BOM manufacturing. This reliance exposes manufacturers to global market volatility and price fluctuations, which can squeeze profit margins and weaken India's competitive positioning relative to international peers. Furthermore, disruptions in global logistics or supply chains can potentially stall the production of critical components despite available domestic manufacturing capacity. The industry also faces customs enforcement challenges, as products are often imported under multiple HS code classifications, making imports difficult to regulate. Together, these challenges constrain the industry's growth by undermining its reliability, limiting technological advancement, and reducing its cost competitiveness relative to global BOM manufacturing hubs.

As India strives to become a global hub for solar manufacturing and an alternative source of high-quality and cost-competitive components for international buyers seeking to diversify their solar supply chains, addressing these challenges will be critical. Domestic BOM manufacturers must prioritise technological diversification and strengthen raw material supply chain resilience to remain market-relevant and reduce financial risks. Simultaneously, government bodies and standard-setting agencies must provide robust regulatory support and establish uniform, international-grade testing standards to ensure consistent quality and bolster buyer confidence across the supply chain. Apart from these supply-side initiatives, the MNRE should extend ALMM and DCR mandates to all BOM components used in domestically produced solar modules. The collective implementation of these measures could contribute to a more resilient solar BOM manufacturing ecosystem while significantly enhancing the global competitiveness of domestic industry players and supporting India's clean energy transition.

> A resilient domestic BOM ecosystem strengthens local solar supply chains and drives global solar manufacturing diversification.

Acronyms

0BB	zero-busbar
AC	alternating current
ADD	anti-dumping duty
AI	artificial intelligence
ALEMAI	Aluminium Extrusion Manufacturers Association of India
ALMM	Approved List of Models and Manufacturers
AR	anti-reflective
ASEAN	Association of Southeast Asian Nations
ASTM	American Society for Testing and Materials
BALCO	Bharat Aluminium Company Ltd
BCD	basic customs duty
BIS	Bureau of Indian Standards
BOM	bill of materials
BSF	back surface field
CAGR	compound annual growth rate
CBIC	Central Board of Indirect Taxes and Customs
CCA	copper-clad aluminium
CIF	cost, insurance, and freight
CPC	coating–PET–coating
CSG	China Southern Glass
CTI	Comparative Tracking Index
CUF	capacity utilisation factor
CVD	countervailing duty
DC	direct current
DCR	Domestic Content Requirement
DGFT	Directorate General of Foreign Trade
DGTR	Directorate General of Trade Remedies
ECMS	*Electronics Component Manufacturing Scheme*
EN	Europäische Norm (German) or European Standard (English)
EPE	EVA–POE–EVA
ETP	electrolytic tough-pitch
EV	electric vehicle
EVA	ethylene-vinyl acetate
FTA	free trade agreement
GAIL	Gas Authority Of India Limited
GST	Goods and Services Tax
HDPE	high-density polyethylene
HJT	heterojunction technology
HS	Harmonised System
IEC	International Electrotechnical Commission
IESS	*India Energy Security Scenarios*
INR	Indian rupee
IOCL	Indian Oil Corporation Ltd
IP	Ingress Protection
IS	Indian Standard
ISO	International Organization for Standardization
ITC	input tax credit

ITRPV	*International Technology Roadmap for Photovoltaics*
LLDPE	linear low-density polyethylene
MBB	multi-busbar
MeitY	Ministry of Electronics and Information Technology
MJ	megajoule
MNRE	Ministry of New and Renewable Energy
MoF	Ministry of Finance
MoPNG	Ministry of Petroleum and Natural Gas
MT	metric tonne
MW	megawatt
NABL	National Accreditation Board for Testing and Calibration Laboratories
NALCO	National Aluminium Company Ltd
NITI Aayog	National Institution for Transforming India
OFC	oxygen-free copper
PA	polyamide
PBIT	profit before interest and tax
PC	polycarbonate
PERC	passivated emitter and rear cell
PET	polyethylene terephthalate
PID	potential-induced degradation
POE	polyolefin elastomer
PPE	polyphenylene ether
PPO	polyphenylene oxide
PV	photovoltaic
PVDF	polyvinylidene fluoride
PVF	polyvinyl fluoride
QCO	quality control order
R&D	research and development
RMB	renminbi
RoHS	*Restriction of Hazardous Substances*
ROCE	return on capital employed
RTV-2	two-component room-temperature vulcanisation
SAMA	Solar Ancillary Manufacturers' Association
SEA	Southeast Asia
TOPCon	tunnel oxide passivated contact
TPO	thermoplastic polyolefin
UV	ultraviolet
VA	vinyl acetate
VAT	value-added tax
WTO	World Trade Organization
WVTR	water vapour transmission rate

References

Alishan Green Energy. 2025a. *Alishan EPE Encapsulant*. Alishan Green Energy. https://www.alishangreenenergy.com/wp-content/uploads/2025/01/Alishan-EPE-Encapsulant.pdf.

Alishan Green Energy. 2025b. *About: Alishan Group*. https://www.alishangreenenergy.com/wp-content/uploads/2025/02/About-Alishan-Group.pdf.

AL Circle. 2026. "Vietnam's first aluminium smelter, Dak Nong, achieves first power delivery milestone." https://www.alcircle.com/news/vietnam-s-first-aluminium-smelter-dak-nong-achieves-first-power-delivery-milestone-119872.

Arkema. n.d. *Performance Characteristics & Data of Kynar PVDF*. Arkema. https://page.arkema.com/rs/253-HSZ-754/images/kynar-pvdf-performance-characteristics-data-brochure.pdf.

Balaji Aluminium Extrusions. 2026. "Aluminium Extrusion Manufacturers Urge Government Relief Over LPG/PNG Shortage." Balaji Aluminium Extrusions. https://www.balajialuminium.com/aluminium-extrusion-manufacturers-urge-government-relief-over-lpg-png-shortage-28-march-2026/.

BALCO (Bharat Aluminium Company Limited). 2026. *Aluminium Primary Metal*. Bharat Aluminium Company Limited. https://d2cwogunyrfjf.cloudfront.net/wp-content/uploads/2026/07/PrimaryAL-PriceList-01.07.2026.pdf.

BigMint. 2025. *Extruding the Future: Aluminium 2025*. ALEMAI. https://alemai.org/assets/frontend/img/whitepapers/pdf/ALUMEX2025_Report_BigMint.pdf.

BigMint. 2026. "Aluminium Scrap Imports Drop 16% Y-o-y in Q1CY'26. Will India Face Tighter Supplies in Q2?" BigMint. https://www.bigmint.co/insights/detail/weekly-round-up-lme-base-metals-mixed-indian-non-ferrous-markets-remain-firm-749060.

BIS (Bureau of Indian Standards). 2020. Safety Glass (Quality Control) Order, 2020. Ministry of Commerce and Industry. https://www.bis.gov.in/wp-content/uploads/2020/03/Safety-Glass-QCO.pdf.

BIS (Bureau of Indian Standards). 2024. *Grant of All India First Licence for "Safety Glass - Specification: Part 3 Solar Applications."* Bureau of Indian Standards. https://www.bis.gov.in/wp-content/uploads/2024/03/IS-2553-Part-3.pdf.

Bluebird Solar. n.d. "Mono PERC Half Cut Solar Panel." Bluebird Solar. https://bluebirdsolar.com/pages/half-cut-solar-panel.

Borosil Renewables. 2020. Specification Sheet. https://borosilrenewables.com/images/products/Borosil-Glass-Specification-01.05.24.pdf.

Borosil Renewables. 2024. *Draft Red Herring Prospectus*. Borosil Renewables. https://www.bseindia.com/corporates/download/486/Rights/Final Borosil Renewables DLOF_20240613152431.pdf.

ChemAnalyst. 2025a. "Polyolefin Elastomer (POE) Price Trend and Forecast in Top 10 Leading Countries Worldwide." ChemAnalyst. https://www.chemanalyst.com/Pricing-data/polyolefin-elastomers-poe-1143.

ChemAnalyst. 2025b. "Ethylene Vinyl Acetate (EVA) Price Trend and Forecast." ChemAnalyst. https://www.chemanalyst.com/Pricing-data/ethylene-vinyl-acetate-74.

Chemico Chemicals. n.d. "Sodium Antimonate." Chemico Chemicals. https://www.chemicochemicals.com/sodium-antimonate.html.

Chien, I-Lung, Tze Wei Kan, and Bo Shuo Chen. 2007. "Dynamic Simulation and Operation of a High Pressure Ethylene-Vinyl Acetate (EVA) Copolymerization Autoclave Reactor." *Computers & Chemical Engineering* 31 (3): 233–45. https://doi.org/10.1016/j.compchemeng.2006.06.007.

Chowdhury, Tamal, Mohammad Dehghanimadvar, Nathan L. Chang, and Richard Corkish. 2025. "Review of Issues and Opportunities for Glass Supply for Photovoltaic Production at Multiterawatt (TW) Scale." *Sustainable Energy & Fuels* 9 (6): 1414–31. https://pubs.rsc.org/en/content/articlehtml/2025/se/d4se01567c.

Creative Ecotech Group. n.d. "GAIL (India) Limited." Creative Ecotech Group. https://creativeecotech.com/gail-india-limited/.

Dhash PV. 2025. "PV Junction Box." https://dhashtec.com/junction-box/.

Dr. Hans Werner Chemikalien. 2023. "Classification of Solar Encapsulants." Dr. Hans Werner Chemikalien. https://www.drhwc.com/en/blogs/classification-of-solar-encapsulants.

DuPont. n.d. *PV Junction Box Potting Agents, Bonding & Sealing*. DuPont. https://www.dupont.com/content/dam/dupont/amer/us/en/photovoltaic/public/documents/DPVS_Fortasun_Tech_Manual_PV_Junction_Box_Reference.pdf.

Electrical Safety Testing Laboratory. 2025a. "IP 67 Waterproof Testing." Electrical Safety Testing Laboratory. https://www.itcindia.org/ip-67-waterproof-testing/.

Electrical Safety Testing Laboratory. 2025b. "IP 68 Upto 5Bar Testing." Electrical Safety Testing Laboratory. https://www.itcindia.org/ip-68-upto-5bar-testing/.

European Parliament and Council of the EU. 2024. "Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem and amending Regulation (EU) 2018/1724." https://eur-lex.europa.eu/eli/reg/2024/1735/oj/eng.

First Solar. n.d. "Products – Series 7." First Solar. https://www.firstsolar.com/en-IN/Products/Series-7.

Gautam Solar. n.d. "Mono PERC Solar Modules." Gautam Solar. https://gautamsolar.com/mono/.

GFL (Gujarat Fluorochemicals Limited). 2018. "Products." Gujarat Fluorochemicals Limited. https://inoflar.com/products.html.

Ghasemi, S., M. A. Schuler, L. E. Alanis, F. Basler, L. C. Rendler, and M. Heinrich. 2025. "Development of Junction Boxes Regarding Modern Wiring Concepts for Future PV Modules." Poster presented at the 42nd European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC). https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/conference-paper/42nd-eupvsec-2025/Ghasemi_3AV122_Poster.pdf.

GoI (Government of India). 2026. *Key to the Budget Document*. Government of India. https://www.indiabudget.gov.in/doc/Key_to_Budget_Document_2026.pdf.

Greenshine. n.d. "Is the Conductivity of Copper Clad Aluminium PV Ribbon Much Different from Pure Copper Ribbon?" Greenshine. https://www.cca-wire.com/is-the-conductivity-of-copper-clad-aluminum-pv-ribbon-much-different-from-pure-copper-ribbon/.

GTRI (Global Trade Research Initiative). 2026. "Flagship Reports." Global Trade Research Initiative. https://gtri.co.in/gtriFlagshipReports.

GWELL. n.d. "EVA POE Encapsulation Film Extrusion Line." GWELL. https://www.gwellextrusion.com/product/eva-solar-film-extrusion-line/eva-poe-encapsulation-film-extrusion-line/.

Heaven Green Energy. 2026. "POE Encapsulant". Heaven Green Energy. https://www.heavengreenenergy.com/glossary/poe-encapsulant.

HyMax. 2023. "Composition of Solar Panels and Application of Hydrolysis Inhibitor in PET Backsheet." HyMax. https://carbodiimide.com/composition-of-solar-panels-and-application-of-hydrolysis-inhibitor-in-pet-backsheet/#The_application_of_hydrolysis_inhibitor_in_PET_backsheet_film_provides_the_following_advantages.

IBM (Indian Bureau of Mines). 2021. *Indian Minerals Yearbook 2021 (Part-II Metals and Alloys) – Antimony*. https://ibm.gov.in/writereaddata/files/169035636264c0ca8ae5273Antimony_2021.pdf.

IEA. 2026. "Copper monthly average price, 1990-2026." https://www.iea.org/data-and-statistics/charts/copper-monthly-average-price-1990-2026.

IEA-PVPS (International Energy Agency Photovoltaic Power Systems Programme). 2014. *Review of Failures of Photovoltaic Modules*. International Energy Agency Photovoltaic Power Systems Programme. https://iea-pvps.org/wp-content/uploads/2020/01/IEA-PVPS_T13-01_2014_Review_of_Failures_of_Photovoltaic_Modules_Final.pdf.

IEC (International Electrotechnical Commission). 2026. "IP Ratings." International Electrotechnical Commission. https://www.iec.ch/ip-ratings.

Indiatlas. 2025. "Limestone Mines in India, Mining, Export, and Imports." Indiatlas. https://indiatlas.com/limestone-mines-in-india-mining/.

IOCL (Indian Oil Corporation Limited). 2026. "Panipat Refinery and Petrochemical Complex." https://iocl.com/pages/panipat-refinery.

Jolywood. 2025. *Jolywood Group Profile*. Jolywood. https://www.jolywood.com/upload/f16e47156276f4b0/6ff1c6ed2cfa9b8a.pdf.

Knack Energy. 2026. "Solar PV Backsheet." https://www.knackenergy.com/products/solar-pv-backsheet/.

Kwon, Da Young, Yerang Park, Jae-Ik Han, Nochang Park, Soohyun Bae, Kyung-Soo Kim, Young-Joo Eo, Gi-Hwan Kang, and Yonghwan Lee. 2025. "Fluorine-Free Transparent Back-

sheets for Low-Carbon Footprint Photovoltaic Modules." *Journal of the Korean Solar Energy Society* 45 (6): 71–79. https://www.ksesjournal.co.kr/articles/article/AzAW/#Information.

Li, Ziyi, Junjie Li, Xiaofan Wang, et al. 2025. "Decarbonizing Photovoltaic Glass Manufacturing in China: A Factory-Specific Carbon Footprint Analysis." *Environmental Technology & Innovation* 40: 104669. https://doi.org/10.1016/j.eti.2025.104669.

Linkwell Electric. 2025. "How to Make a Junction Box: Junction Box Manufacturing Process." Linkwell Electric. https://linkwellelectrics.com/how-to-make-a-junction-box/.

Maguire. 2020. "Energy Efficient Drying of Pellets Using Vacuum: Part 1." Maguire. https://www.maguire.com/news/energy-efficient-drying-of-pellets-using-vacuum-part-1-1/.

MeitY (Ministry of Electronics and Information Technology). 2026. "Electronics Component Manufacturing Scheme." Ministry of Electronics and Information Technology. https://ecms.meity.gov.in/.

Mercom India. 2024. "DhaSh PV to Build INR 3.46 Billion Solar Junction Box Plant in Karnataka." Mercom India. https://www.mercomindia.com/dhash-pv-solar-junction-box-plant-in-karnataka.

Mercom India. 2025a. "Borosil Hurt by Cheaper Chinese Solar Glass, Loss Widens in Q3 FY 2025." Mercom India. https://www.mercomindia.com/borosil-hurt-by-cheaper-chinese-solar-glass-loss-widens-in-q3-fy-2025.

Mercom India. 2025b. "India Must Build a Resilient Domestic Supply Chain for BoS Components." Mercom India. https://www.mercomindia.com/india-resilient-domestic-supply-chain-bos-components.

Migo Glass. n.d. Solar glass. https://www.migoglass.com/solar-glass/ar-coating-solar-glass/low-iron-patterned-tempered-photovoltaic-glass.html.

MNRE (Ministry of New and Renewable Energy). 2025. *Guidelines for Series Approval of SPV Modules for Conducting Testing in Test Labs for Implementation of Solar Systems, Devices and Components Goods Order, 2025*. Ministry of New and Renewable Energy. https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2025/08/202508141931213985.pdf.

MNRE (Ministry of New and Renewable Energy). 2026a. *Updation of List I (Manufacturers and Models of Solar PV Modules) of ALMM Order, 2019 - Reg*. Ministry of New and Renewable Energy. https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2026/09/202609161469951718.pdf

MNRE (Ministry of New and Renewable Energy). 2026b. *Publishing 12th Revision of ALMM (Approved List of Models & Manufacturers) LIST - II (for Solar PV Cells) -Reg*. Ministry of New and Renewable Energy. https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2026/10/202610091229460604.pdf.

MoCI (Ministry of Commerce and Industry). 2014. "Indian Trade Portal." Ministry of Commerce and Industry. https://indiantradeportal.in/vs.jsp?pid=1&txthscode=&txtproduct=junction+box&btnSubmit=Search.

MoCI (Ministry of Commerce and Industry). 2015. "Indian Trade Portal." Ministry of Commerce and Industry. https://indiantradeportal.in/vs.jsp?pid=2&productID=37032.

MoCI (Ministry of Commerce and Industry). 2019. *Anti-Dumping Investigation Concerning Imports of "Ethylene Vinyl Acetate (EVA) Sheet for Solar Module" from China PR, Malaysia, Saudi Arabia, South Korea and Thailand*. Directorate General of Trade Remedies. https://dgtr.gov.in/sites/default/files/2024-08/Final_Finding_Notification_English.pdf.

MoCI (Ministry of Commerce and Industry). 2022. *Anti-Dumping Investigation Concerning Imports of Fluoro Backsheet Originating in or Exported from China PR*. Directorate General of Trade Remedies. https://dgtr.gov.in/sites/default/files/2024-08/FF%20NCV%20English%20%283%29.pdf.

MoCI (Ministry of Commerce and Industry). 2023a. *Sunset Review Investigation Concerning Imports of Textured Tempered Coated and Uncoated Glass from Malaysia*. Directorate General of Trade Remedies. https://dgtr.gov.in/sites/default/files/2024-08/Final Findings - TTG NCV 25.11.2023.pdf.

MoCI (Ministry of Commerce and Industry). 2023b. "Anti-Dumping Investigation Concerning Imports of 'Ethylene Vinyl Acetate (EVA) Sheet for Solar Module' from China PR, Malaysia, Saudi Arabia, South Korea and Thailand." Directorate General of Trade Remedies. https://www.dgtr.gov.in/en/anti-dumping-cases/anti-dumping-investigation-concerning-imports-ethylene-vinyl-acetate-eva-sheet.

MoCI (Ministry of Commerce and Industry). 2024a. *Anti-Dumping Investigation Concerning Imports of "Anodized Aluminium Frames for Solar Panels/Modules" Originating in or Exported from China PR*. Directorate General of Trade Remedies. https://dgtr.gov.in/sites/default/files/2024-08/FF%20NCV%20aluminium%20frames%2029.6.2024.pdf.

MoCI (Ministry of Commerce and Industry). 2024b. *Anti-Dumping Duty on Ethylene Vinyl Acetate (EVA) Sheet for Solar Module from China*. Ministry of Commerce and Industry. https://worldtradescanner.com/05-ADD-14.03.2024.htm.

MoCI (Ministry of Commerce and Industry). 2025a. "Directorate General of Trade Remedies." Directorate General of Trade Remedies. https://www.dgtr.gov.in/en/anti-dumping-investigation-in-india.

MoCI (Ministry of Commerce and Industry). 2025b. *Anti-Dumping Investigation Concerning Imports of "Textured Tempered Coated and Uncoated Glass" Originating in or Exported from China PR and Vietnam*. Directorate General of Trade Remedies. https://dgtr.gov.in/sites/default/files/2025-02/TTG_FF%20-NCV%20-%20ENGLISH_0001-.pdf.

MoCI (Ministry of Commerce and Industry). 2025c. "Countervailing Duty Investigation Concerning Imports of 'Textured Tempered Coated and Uncoated Glass' Originating in or Exported from Vietnam." Directorate General of Trade Remedies. https://www.dgtr.gov.in/en/countervailing-duty-investigation/countervailing-duty-investigation-concerning-imports-textured.

MoCI (Ministry of Commerce and Industry). 2026a. "Trade Statistics." Ministry of Commerce and Industry. https://tradestat.commerce.gov.in/eidb/commodity_wise_all_countries_import.

MoCI (Ministry of Commerce and Industry). 2026b. "Anti-Subsidy Investigation Concerning Imports of Textured Tempered Glass Whether Coated or Uncoated from Malaysia." Directorate General of Trade Remedies. https://www.dgtr.gov.in/en/countervailing-duty-investigation/anti-subsidy-investigation-concerning-imports-textured-tempered.

MoCI (Ministry of Commerce and Industry). 2026c. *Final Finding in Sunset Review Investigation of Countervailing Duty/Anti-Subsidy Concerning Imports of "Textured Tempered Glass" Originating in or Exported from Malaysia*. Directorate General of Trade Remedies. https://dgtr.gov.in/sites/default/files/2026-03/TTG_Eng_NCV_Sign%20%281%29.pdf.

MoCI (Ministry of Commerce and Industry). 2026d. "Anti-Dumping Investigation Concerning Imports of 'Aluminium Frame for Solar Panels/Modules' Originating in or Exported from China PR." Directorate General of Trade Remedies. https://www.dgtr.gov.in/en/anti-dumping-cases/anti-dumping-investigation-concerning-imports-aluminium-frame-solar.

MoCI (Ministry of Commerce and Industry). 2026e. "Anti-Dumping Investigation Concerning Imports of 'Solar Encapsulants' Originating in or Exported from South Korea, Thailand and Vietnam." Directorate General of Trade Remedies. https://www.dgtr.gov.in/en/anti-dumping-cases/anti-dumping-investigation-concerning-imports-solar-encapsulants-originating-or.

MoF (Ministry of Finance). 2017. *Notification No.1/2017 – Central Tax (Rate)*. Ministry of Finance. https://gstcouncil.gov.in/sites/default/files/2024-05/download_4_0.pdf.

MoF (Ministry of Finance). 2022. *Notification No. 22/2022-Customs (ADD)*. Ministry of Finance. https://taxinformation.cbic.gov.in/view-pdf/1009345/ENG/Notifications.

MoF (Ministry of Finance). 2024a. *Notification No. 34/2024-Customs*. Ministry of Finance. https://www.indiabudget.gov.in/budget2024-25/doc/cen/cus342024.pdf.

MoF (Ministry of Finance). 2024b. *Notification No. 16/2024-Customs (ADD)*. Ministry of Finance. https://taxinformation.cbic.gov.in/view-pdf/1010162/ENG/Notifications.

MoF (Ministry of Finance). 2025a. *Notification No. 07/2025-Customs (CVD)*. Ministry of Finance. https://dgtr.gov.in/sites/default/files/2025-12/notification%207%20of%202025%20cvd.pdf.

MoF (Ministry of Finance). 2025b. *Union Budget 2024–2025*. Ministry of Finance. https://www.indiabudget.gov.in/doc/bspeech/bs2024_25.pdf.

MoF (Ministry of Finance). 2025c. *Recommendations of the 56th Meeting of the GST Council Held at New Delhi, Today*. Press release, September 3. Press Information Bureau. https://gstcouncil.gov.in/sites/default/files/2025-09/press_release_press_information_bureau_0.pdf.

MoF (Ministry of Finance). 2025d. Notification No. 11/2025-Customs (ADD). Ministry of Finance. https://taxinformation.cbic.gov.in/view-pdf/1010375/ENG/Notifications.

MoF (Ministry of Finance). 2026a. *Notification No. 02/2026-Customs*. Ministry of Finance. https://www.indiabudget.gov.in/doc/cen/cus0226.pdf.

MOFCOM (Ministry of Commerce of the People's Republic of China). 2025. *Ministry of Commerce and General Administration of Customs Announcement No. 58 of 2025 on the Implementation of Export Controls on Items Related to Lithium Batteries and Artificial Graphite Anode Materials*. Ministry of Commerce of the People's Republic of China. https://www.mofcom.gov.cn/zwgk/zcfb/art/2025/art_79646f0161564975a938fe00fee158d5.html.

MOF China (Ministry of Finance of the People's Republic of China). 2026. "Announcement on Adjusting Export Tax Rebate Policies for Photovoltaic Products and Other Products." Ministry of Finance of the People's Republic of China. https://szs.mof.gov.cn/zhengcefabu/202601/t20260109_3981637.htm.

Mordor Intelligence. 2026. "Solar Photovoltaic Glass Market Size and Share Analysis." Mordor Intelligence. https://www.mordorintelligence.com/industry-reports/solar-photovoltaic-glass-market.

NALCO (National Aluminium Company Limited). 2026. "Current Price (Metal)." National Aluminium Company Limited. https://nalcoindia.com/domestic/current-price/.

NITI Aayog. 2023. "India Energy Security Scenarios (IESS) 2047 V3.0", Government of India. https://iess2047.gov.in/_/theme/documents/IESS_v3_one_pagers.pdf.

Novanext. 2025. *Novanext Catalogue*. Novanext. https://novanextenergies.com/catalogue.pdf.

Office of the Principal Commissioner of Customs. 2023. *Show Cause Notice*. Office of the Principal Commissioner of Customs. https://gujaratcustoms.gov.in/juridictional_commissionerate/public/storage/pdfs/WhHXOsGNXPkhhQXPGWshEBUVW8ixRyKj0RjI4Bci.pdf.

PIB Delhi (Press Information Bureau, Delhi). 2026. *Government Approves 29 More Proposals under the Electronics Component Manufacturing Scheme (ECMS)*. Press Information Bureau. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2247040&reg=3&lang=2.

PV Magazine. 2025. "Backsheet Buoyed PV Manufacturers." *PV Magazine*, February 19. https://www.pv-magazine.com/2025/02/19/backsheet-buoyed-pv-manufacturers/.

PV Magazine India. 2025. "Beyond Aluminium: How Composite Frames Are Redefining the Solar Module Landscape." *PV Magazine*, May 29. https://www.pv-magazine-india.com/2025/05/29/beyond-aluminum-how-composite-frames-are-redefining-the-solar-module-landscape/.

PV Magazine India. 2026. "Solar Modules under Pressure: The Growing Risk of Spontaneous Glass Breakage." *PV Magazine*, January 19. https://www.pv-magazine-india.com/2026/01/19/solar-modules-under-pressure-the-growing-risk-of-spontaneous-glass-breakage/.

Raytron. 2024. "PV Ribbon." Raytron. https://raytron.co/applications/pv-ribbon/.

Rediff. 2026. "Aluminium Industry Faces LPG/PNG Shortages." Rediff. https://money.rediff.com/news/market/aluminium-industry-faces-lpg-png-shortages/44095620260324.

RenewSys. 2025a. *RenewSys CONSERV U+ Encapsulant Datasheet*. RenewSys. https://9021fdc6-0afa-473e-b60c-1dbccce51d7c.filesusr.com/ugd/84a06c_2818c2bacf374ab38476ffb910a01a4a.pdf.

RenewSys. 2025b. *RenewSys Preserv A - WN1*. RenewSys. https://9021fdc6-0afa-473e-b60c-1dbccce51d7c.filesusr.com/ugd/84a06c_753fdf23c48a490b98ac5850dff32303.pdf.

RenewSys. 2026. "Backsheet Downloads Preserv." RenewSys. https://www.renewsysworld.com/backsheet-downloads-preserv.

Saatvik Green Energy. n.d. *Bifacial - MONO PERC - 144 Cells*. Saatvik Green Energy. https://saatvikgroup.com/wp-content/uploads/2024/11/BIFACIAL-MONO-PERC-144-Cells-2-2.pdf.

Sekhani. 2024. "PV Bus Bar." Sekhani. https://www.sekhanirenewables.com/pv-bus-bar.php.

Shanghai Metals Market. 2026a. "Photovoltaic Frame." Shanghai Metals Market. https://www.metal.com/photovoltaic/202207050003.

Shanghai Metals Market. 2026b. "SMM China PV-Grade EVA Price, USD/Tonne." Shanghai Metals Market. https://www-old.metal.com/photovoltaic/202208170001.

Shini USA. n.d. "Everything You Need to Know About Desiccant Drying." Shini USA. https://www.shiniusa.com/2016/07/26/everything-you-need-to-know-about-desiccant-drying/.

Sinonine. 2021. "Standard and Production of Photovoltaic Glass Sand." Sinonine. https://www.9silica.com/NEWS/Newslist/225.html.

SpecialChem. 2022. *Relene EVA 1802*. SpecialChem. https://www.specialchem.com/plastics/product/reliance-industries-relene-eva-1802.

Sumati Electronics. n.d.a. "Reflective PV Bus Bar." Sumati Electronics. https://sumatielectronics.com/reflective-pv-bus-bar/.

Sumati Electronics. n.d.b "PV Wire." Sumati Electronics. https://pvribbon.in/multi-busbar-pv-wire.html.

Taiyang News. 2025. *TaiyangNews Solar Backsheets & Encapsulants Market Survey 2024/25*. Taiyang News. https://taiyang-news.info/reports/solar-backsheets-encapsulants-market-survey-202425.

TE Connectivity. n.d. *SOLARLOK PV Edge Decentralized Junction Box*. TE Connectivity. https://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocFormat=pdf&DocLang=English&DocNm=1-1773904-6_SOLARLOK_PV_Edge_Junction_Bo&DocType=-Data+Sheet&PartCntxt=2213759-3.

Telison. n.d. "Industrial Distribution." Telison. https://en.telison.com/product/41.html.

Turaev, Farkhodjon, Isroil Yuldoshev, Khimmatali Juraev, Bozrbek Botirov, Sadullo Fazliddinov, and Shakhnoza Rustamova. 2026. "Local Overheating of a Photovoltaic Module Junction Box: Analysis and Recommendations." *Clean Energy* 10 (1): 29–35. https://academic.oup.com/ce/article/10/1/29/8273668.

Tyagi, Akanksha, Prashant Badal and Ajinkya Kale. 2025. *How Big is the Solar Module Recycling Industry in India? Sizing the Market, Investment, and Emission Reduction Opportunity*. New Delhi: Council on Energy, Environment and Water. https://www.ceew.in/publications/solar-module-waste-and-recycling-roadmap-by-2047.

Ulbrich. n.d. "Ulbrich Solar Technologies." Ulbrich. https://www.pvribbon.com/.

Valeo. n.d. "Tinned Copper Interconnect / Tabbing Ribbon." Valeo. https://valeoproducts.com/tabbing-ribbon-solar-wire-cell-connector/.

VDMA (Verband Deutscher Maschinen- und Anlagenbau). 2025. *International Technology Roadmap for Photovoltaics (ITRPV), 16th ed*. Verband Deutscher Maschinen- und Anlagenbau. https://www.vdma.org/international-technology-roadmap-photovoltaic.

Vidya Wires. n.d. "PV Round Ribbon." Vidya Wires. https://www.vidyawire.com/product/pv-round-ribbon/.

Vikram Solar. n.d. "Suryava." Vikram Solar. https://www.vikramsolar.com/products/suryava-700-725w-132-cell/.

Vishakha Renewables. 2025a. *Vishakha POE Technical Datasheet*. Vishakha Renewables. https://vishakharenewables.com/wp-content/uploads/2026/04/technical_datasheet_encapsulant_vishakha_poe.pdf.

Vishakha Renewables. 2025b. *Vishakha 1500 V PET*. Vishakha Renewables. https://vishakharenewables.com/wp-content/uploads/2026/07/technical_datasheet_backsheet_vishakha_1500V_pet.pdf.

Vishakha Renewables. 2026. "Solar Backsheet." Vishakha Renewables. https://vishakharenewables.com/products/solar-backsheet/.

Vishakha Renewables. n.d. "Product Specification - Low Iron Solar Textured Glass." https://vishakharenewables.com/certifications/Technical-Vishakha-Glass-Private-Limited.pdf

Volberg, Guido. n.d. *Junction Boxes for Photovoltaic Modules – Qualification and Tests*. PV Tech. https://www.pv-tech.org/wp-content/uploads/legacy-publication-pdfs/cbeb6e199d-junction-boxes-for-photovoltaic-modules-qualification-and-tests.pdf.

Waaree Energies. n.d. "Mono PERC." Waaree Energies. https://waaree.com/solar-pv-modules/mono-perc/.

Wallner, Gernot M., Baloji Adothu, Robert Pugstaller, Francis R. Costa, and Sudhansu Mallick. 2022. "Comparison of Crosslinking Kinetics of UV-Transparent Ethylene-Vinyl Acetate Copolymer and Polyolefin Elastomer Encapsulants." *Polymers* 14 (7): 1441. https://pmc.ncbi.nlm.nih.gov/articles/PMC9003555/.

Webel Solar. n.d. *Module Manufacturing and Testing*. Webel Solar. https://www.ncpre.iitb.ac.in/ncpre/uploads/Module_Manufacturing_and_Testing_Anupam_Sharma.pdf.

WTO (World Trade Organization). 1994. *Agreement on Implementation of Article VI of the General Agreement on Tariffs and Trade 1994*. World Trade Organization. https://www.worldtradelaw.net/document.php?id=uragreements%2Fadagreement.pdf&mode=download.

WTO Center. 2016. "ASEAN – India Free Trade Area." WTO Center. https://wtocenter.vn/chuyen-de/12786-asean---india-free-trade-area.

Xinyi Solar. 2026. "Xinyi Solar Announces 2026 Interim Results." *Xinyi Solar*, July 31. https://www.xinyisolar.com/en/NewsCenter/info.aspx?itemid=939.

Zier, Michael, Peter Stenzel, Leander Kotzur, and Detlef Stolten. 2021. "A Review of Decarbonization Options for the Glass Industry." *Energy Conversion and Management*: X 10: 100083. https://doi.org/10.1016/j.ecmx.2021.100083.

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