INDIA'S SOLAR MANUFACTURING ECOSYSTEM

A LANDSCAPE STUDY

Research direction: Avantika Goswami

Authors: Trishant Dev and Kushal Kabra

Editor: Archana Shankar

Cover: Ajit Bajaj

Graphics: Tarun Sehgal and Vineet Tripathi

Production: Rakesh Shrivastava and Gundhar Das

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41, Tughlakabad Institutional Area
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Phone: 91-11-40616000
Fax: 91-11-29955879
E-mail: cse@cseindia.org
Website: www.cseindia.org

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Executive summary

Solar photovoltaics is now the fastest-growing source of new electricity capacity worldwide, and the manufacturing base behind it has become a strategic industry in its own right. China dominates every stage of the value chain, holding about 93 per cent of global polysilicon capacity and 97 per cent of wafer capacity. This study maps where India stands across the five core stages (polysilicon, ingots, wafers, cells and modules), the policies shaping its growth, and the choices ahead.

A base that narrows sharply upstream. As of August 2026, India has over 219 GW of ALMM-notified module capacity but only 31 GW of cell capacity, 2 GW of wafer capacity and no polysilicon production. Module imports fell from US $4.35 billion in 2023–24 to under US $1 billion in 2025–26. Over the same period, cell imports rose from US $1.85 billion to about US $3 billion. Import dependence has moved up the value chain rather than disappeared. Much of the cell capacity still uses PERC technology even as the global industry shifts to TOPCon. Key components such as silver paste, solar glass, encapsulants, backsheets and aluminium frames remain substantially imported.

A persistent cost gap. Before duties, Indian modules cost 25–35 per cent more than Chinese modules. Import duties largely close this gap on a landed-cost basis, but they do not remove its sources. These include duties on imported cells and inputs, an import-dependent component ecosystem, plants operating at a fraction of Chinese scale, and costlier power and capital.

Capacity has run ahead of incentives. The Production Linked Incentive (PLI) scheme, with an outlay of Rs 24,000 crore, had disbursed no funds as of July 2026. PLI-backed firms account for only about 30 GW of module capacity, so most investment has happened outside the scheme.

The price of localization. ALMM List-II, in force from 1 June 2026, extends domestic-content requirements from modules to cells. Together with List-I, it adds an estimated Rs 32,500–37,900 crore to solar procurement costs in FY2026–27. That is more in a single year than the entire PLI outlay. This cost may be worth bearing, but only if it has a defined horizon and yields lasting gains in capability and resilience.

Trade pressures on both fronts. In May 2026, China sought a WTO panel to challenge India's tariff regime and elements of the PLI scheme. The United States, India's largest solar export market, imposed preliminary countervailing duties of around 126 per cent and anti-dumping duties of 123 per cent on Indian cells and modules in 2026.

What comes next. The study closes with three questions for the next phase of policy:

1. Protection. Should protection be tied to measurable gains in scale, supplier capacity and cost competitiveness?

2. How far upstream? A competitive polysilicon plant needs US $1–1.2 billion in capital. Could resilience come from domestic capacity at selected stages, such as wafers, combined with diversified sourcing?

3. Where to direct support? Should support shift from manufacturers who would likely have invested anyway towards equipment, materials and components, where private investment has not materialized on its own?

INTRODUCTION

Solar is now a major global investment destination, attracting $365 billion in 2025.

The solar value chain spans five stages: polysilicon, ingots, wafers, cells and modules, with the upstream stages more capital- and energy-intensive.

India's manufacturing remains concentrated downstream, leaving significant dependence on imported upstream inputs.

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Solar manufacturing in the global energy transition

Solar photovoltaic (PV) technology has become a defining technology of the global energy transition. The International Energy Agency's World Energy Investment Report 2026 estimates that approximately US $665 billion was invested globally in renewable energy projects in 2025, of which around US $365 billion was directed towards solar power alone, equivalent to nearly US $1 billion in investment every day. Driven by falling costs, improving efficiencies, and growing energy security concerns, solar PV has emerged as the fastest-growing source of new electricity generation capacity worldwide.

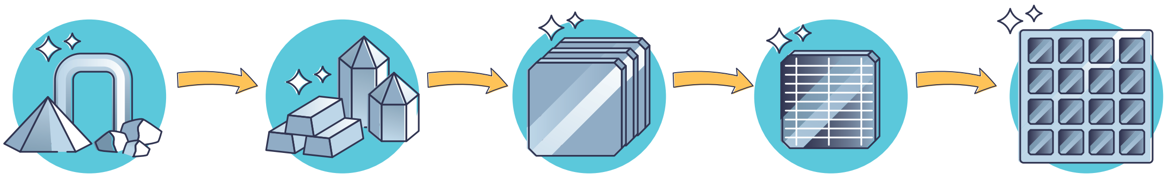
The crisis in West Asia has further accelerated the shift towards alternative energy sources, with solar imports from China into Asian and African countries registering record jumps in recent months. Solar PV exports from China to Africa and Asia jumped by 120 per cent and 150 per cent, respectively, in the first quarter of 2026 compared to the same period in 2025.

The manufacturing ecosystem behind solar deployment has become a strategic industrial sector in its own right. Manufacturing creates technological capabilities, adds domestic value, generates employment, and attracts investment. Most importantly, it reduces dependence on any one country for supplying critical inputs.

For India, meeting its clean energy ambitions entails not only deploying solar power at scale but also building a globally competitive domestic manufacturing ecosystem. Doing so can reduce strategic dependence on imports, particularly from China, strengthen technological and industrial capabilities, capture a greater share of value creation, generate skilled employment, and ensure a secure, affordable, and resilient supply chain for the country's energy transition. Moreover, there is potential to develop alternate economies as high-carbon sectors have to eventually wind down in achievement of India's climate goals, and low-carbon manufacturing sectors need to grow to absorb jobs and value creation.

Against this backdrop, this paper examines India's solar manufacturing ecosystem across the major stages of the solar PV value chain. It assesses the current status of domestic manufacturing capabilities in polysilicon, wafers, cells, and modules, and analyses the technological, economic, and policy constraints that shape their development. The study also evaluates the extent to which India's manufacturing expansion has contributed to investment, employment and domestic value addition, while examining persistent import and export dependencies and the

Figure 1: Solar PV manufacturing value chain



Source: IEA

challenges associated with moving upstream into higher-value manufacturing segments.

Understanding the solar PV value chain

Solar photovoltaic manufacturing consists of a series of interconnected production stages, each characterized by different technological requirements, capital intensity, value addition, and supply-chain dynamics. At its simplest, the solar PV value chain comprises five core manufacturing stages: polysilicon, ingots, wafers, cells, and modules (see *Figure 1: Solar PV manufacturing value chain*).

The value chain begins with silica, one of the most abundant minerals on earth, which is refined into metallurgical-grade silicon and subsequently processed into solar-grade polysilicon. Polysilicon serves as the primary raw material for crystalline silicon solar cells, the dominant technology used in solar PV systems worldwide. Polysilicon is melted and formed into cylindrical or rectangular ingots, which are then sliced into thin wafers. These wafers form the substrate on which photovoltaic cells are manufactured through a series of processes, including doping, texturing, metallization and anti-reflective coating. Individual cells are then interconnected and assembled into modules, which are subsequently integrated into solar power systems (see *Figure 2: Simplified manufacturing from raw materials for crystalline silicon and cadmium telluride-based solar PV systems*).

From an industrial perspective, these stages fall into three broad segments: upstream, midstream, and downstream manufacturing. Upstream manufacturing includes polysilicon, ingot and wafer production, which are highly capital-intensive, energy-intensive and technologically complex. Midstream manufacturing primarily comprises solar cell production, where process innovation and manufacturing efficiency are critical determinants of competitiveness. Downstream manufacturing consists of module assembly, which typically involves lower technological barriers

Figure 2: Simplified manufacturing from raw materials for crystalline silicon and cadmium telluride-based solar PV systems

CRYSTALLINE SILICON
Mineral extraction
Silica (SiO_2): quartzite, quartz pebble, quartz vein
Carbothermic reduction (carbon arc welding [CAW]), removal of impurities
Metallurgical-grade silicon (MG-Si >98% purity)
Hydrochloration
Trichlorosilane gas ($HSiCl_3$)/Silane gas (SiH_4)
Siemens process / Fluidised bed reactor (FBR)
Polysilicon (6–13N purity)
Czochralski (CZ) process/float zone (FZ) technique /molding (heat exchange method/electro-magneto casting/directional solidification system), **doping**
Monocrystalline silicon ingot/multicrystalline, mono-like or quasi-mono silicon ingot
Sawing and slicing
Wafers
Cleaning, texturing, doping (diffusion), etching, anti-reflective coating deposition, contact printing and sintering, testing
Cells
Backsheet, contacts, encapsulation, glass and frame assembly and sealing, junction box connection, testing
Module
Mounting, inverter connection, connection to the grid
PV system

THIN FILM (CdTe)
Mineral extraction and refining
Cadmium (Cd), tellurium (Te), etc.
Deposition of a transparent conducting oxide (TCO) (e.g. fluorine-doped tin oxide or indium-tin oxide) front contact layer on a substrate (e.g. glass, polymer)
Deposition of a n-type cadmium sulphide (CdS) buffer or window layer
Deposition of a p-type cadmium telluride (CdTe) absorber layer
Junction-activation heat treatment
Deposition of the back contact metal layers (e.g. zinc telluride [ZnTe], molybdenum [Mo])
Definition of cells by laser scribing, interconnection bussing
Cells
Encapsulation, electrical lead attachment, junction box connection, testing
Module
Mounting, inverter connection, connection to the grid
PV system

Source: IEA

but remains important for employment generation, domestic value addition, and market development.

India's manufacturing capabilities currently remain concentrated in the downstream segments of the value chain, particularly modules and, increasingly, cells. However, dependence on imports persists for several upstream inputs and intermediate products. Understanding the structure of the solar PV value chain is therefore essential to assess India's current manufacturing position, identify supply-chain vulnerabilities, and evaluate the opportunities and challenges of deeper industrial integration.

2

STAGE-WISE ANALYSIS OF SOLAR MANUFACTURING

India's capacity drops sharply upstream: 219 GW of modules, 31 GW of cells, 2 GW of wafers and no commercial polysilicon capacity.

Cell and module manufacturing is scaling, but technology gaps, import dependence and higher production costs persist.

Critical components remain import-dependent, limiting domestic value addition beyond cells and modules.

1. Raw materials: silica and critical minerals

Before turning to the four processing stages of the value chain, this section reviews the raw material base—the silica feedstock from which polysilicon is made and the critical minerals used across solar PV technologies.

Availibility of silica

Raw material availability is unlikely to be India's primary constraint in polysilicon manufacturing. While most silica sand deposits are unsuitable for solar-grade silicon production, India has significant reserves of high-purity vein quartz, the preferred feedstock for metallurgical-grade silicon. Rajasthan accounts for roughly 55 per cent of national quartz production, followed by Telangana with around 28 per cent, while Haryana hosts substantial quartz and quartzite reserves. Domestic quartz is largely used for ferrosilicon, steel, and other industrial applications rather than high-purity silicon production.[1,2]

Quartz → Metallurgical-grade silicon (MG-Si) → Trichlorosilane → Polysilicon

In FY2023–24, India exported nearly 1.5 million tonnes of quartz and quartzite, while importing over 85,000 tonnes of silicon and other silicon products, primarily outside the solar-grade polysilicon category.

Critical minerals for solar PV: Where does India stand?

Different solar PV technologies depend on different critical minerals:

- Crystalline silicon technology rests on silicon;
- Thin-film and advanced cell architectures depend on tellurium (the cadmium telluride modules of the kind produced in Tamil Nadu by First Solar);
- Indium (transparent oxides used in HJT cells and in advanced Copper Indium Gallium Selenide (CIGS), a thin-film PV technology;
- Gallium is used as a dopant in p-type silicon and as a constituent of CIGS and III-V semiconductor technologies. Gallium is also one of India's identified critical minerals, although its availability as a geological resource does not necessarily translate into domestic production of refined gallium. The Geological Survey of India has identified resources of 74 million tonnes of gallium-bearing ore.[3]

All four minerals—silicon, tellurium, indium and gallium—figure in the list of 30 critical minerals identified by the Ministry of Mines in 2023.[4]

For silicon, as discussed, the principal constraint appears to be refining and processing capability rather than the availability of suitable mineral resources. Quartz is exported in bulk while refined silicon is imported.

Tellurium is recovered primarily as a by-product of copper refining, particularly from copper anode slimes. India has a substantial copper-smelting and refining industry, providing a potential domestic recovery route. However, the Ministry of Mines' critical-minerals assessment identifies no domestic tellurium production, while government-supported R&D is currently examining the recovery of tellurium from processed copper-refinery anode slimes.[5]

Indium is primarily recovered as a by-product of zinc processing. India has a large and integrated zinc industry, with Hindustan Zinc being the world's largest integrated zinc producer. However, domestic indium recovery does not appear to have been commercialized at meaningful scale.

Gallium can be recovered from the liquor streams produced during alumina refining. India has a substantial alumina industry, but the available evidence indicates a gap in the commercial recovery and refining of gallium.

In each case, the feedstock flows through industry as a by-product stream of aluminium, zinc and copper.

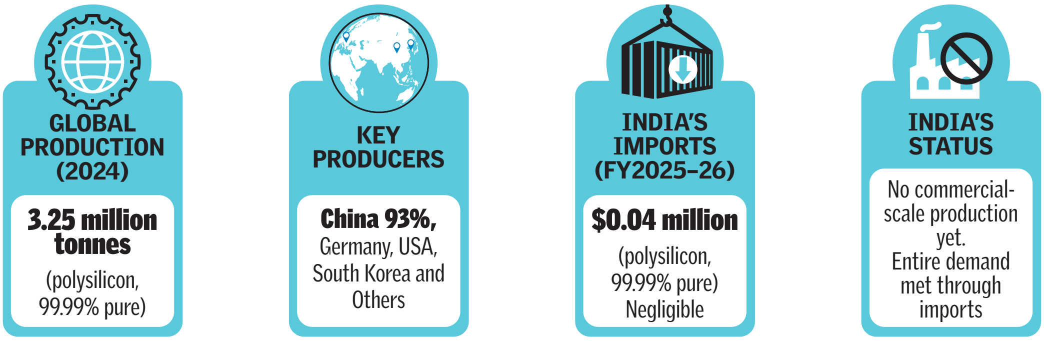
China dominates the refining of all four and has progressively exploited that advantage.

It introduced export licensing requirements for gallium and germanium in 2023 and subsequently imposed restrictions on exports of gallium and germanium to the United States in 2024. In 2025, China introduced export controls covering specified items and technologies related to tungsten, tellurium, bismuth, molybdenum and indium.[6]

India's policy response has come through its National Critical Mineral Mission, approved in 2025 with an outlay of 16,300 crore, alongside public sector investments, including the recovery of minerals such as gallium and tellurium and incentivizing recycling from secondary sources.

2. Polysilicon

Figure 3: Polysilicon: India's position in the global value chain



Source: CSE (compiled from various sources)

Technology landscape

Polysilicon is the foundational input in the solar PV value chain, forming the basis for ingot, wafer and ultimately cell and module production. Its manufacturing is technologically complex and highly energy-intensive, making it one of the most capital- and capability-intensive segments of solar industrialization. The dominant production route is the Siemens process, which produces solar-grade polysilicon with purity levels exceeding 99.9999 per cent, but requires 45–55 kWh of electricity for every kilogram of polysilicon output. Depending upon process modification, this could climb to 60–70 kWh of electricity consumed. This typically accounts for 30–40 per cent of total production costs. Thus, the cost of production is sensitive to electricity prices.

An alternative, the fluidized bed reactor (FBR) process, reduces energy consumption; however, it has faced challenges in impurity control and consistent output quality at scale. It also requires higher capital investment. The share of FBR polysilicon increased from 2 per cent in 2020 to 15 per cent in 2024.[7]

Table 1: Typical production cost structure of polysilicon in China

Item	Proportion range (%)	Specific Value Estimate (based on $6.5/kg total cost) (in $)	Key influencing factors
Electricity/energy	35–40	2.30–2.60	Electricity price (every $0.01/kWh fluctuation affects $0.55/kg)
Metallic silicon raw material	30–35	1.95–2.30	Mining and smelting supply and demand
Depreciation/amortization	15–20	1.00–1.30	Initial CapEx and capacity utilization rate
Labour/maintenance	10–12	0.65–0.80	Automation degree

Source: Tongwei Solar[8]

Production geography

At the end of 2024, China accounted for approximately 93.5 per cent of global polysilicon output, with nine of the world's ten largest polysilicon manufacturers based in the country. The top six companies, Tongwei, GCL Technology, Daqo New Energy, Xinte Energy, Qinghai Lihao Qingneng and Xinjiang East Hope, collectively accounted for an estimated 2.5 million tonnes of production capacity by the end of the year, out of China's total capacity of roughly 3.25 million tonnes.[9,10]

Outside China, polysilicon production remains limited and geographically concentrated. Key producers include Wacker Chemie in Germany (around 80,000 tonnes), Hemlock Semiconductor in the United States (around 35,000 tonnes), and OCI Company in Malaysia (around 39,000 tonnes). More recently, new capacity has emerged in Oman, with United Solar Polysilicon announcing a production capacity of approximately 100,000 tonnes.[11]

In India, there is currently no commercial-scale production of polysilicon.[12] Several proposed projects have been delayed, scaled back or cancelled, as the decline in global polysilicon prices has weakened the business case for domestic production.[13]

Trade landscape in India

Trade in solar-grade polysilicon does not form a substantial part of the solar PV manufacturing ecosystem as very little wafer-ingot manufacturing takes place in the country.

Table 2: India's solar-grade polysilicon import and exports[14]

Import (a)

Financial year	Import value (US$ million) (HS:28046100)	Import quantity (tonnes)	Countries
2022–23	0.63	14.7	Malaysia (73.5%), US (25.8%), Spain (0.2%)
2023–24	8.17	831	China (99.3%), Taiwan (0.7%)
2024–25	0.03	0.029	France (66%)
2025–26	0.04	0.586	Japan (50%), US (25%), Germany (21%)

Export (b)*

Financial year	Export value (US$ million) (HS:28046100)	Export quantity (tonnes)	Countries
2020–21	0.01	3.5	UAE (85%), Kenya (6%), Oman (6%)
2021–22	0.13	34.3	Tanzania (37.8%), UAE (26%), Mozambique (23.3%)
2022–23	0.07	43.6	Nepal (76%), Senegal (11.4%), Togo (11.4%)

*The small export volumes in Table 2(b) do not indicate domestic solar-grade polysilicon production. Exports were only 3.5–43.6 tonnes per year, worth less than US $0.15 million, and were directed mainly to countries without significant wafer manufacturing. These shipments are therefore more likely to reflect re-exports of imported material, silicon scrap, or differences in customs classification. This is consistent with the absence of commercial-scale polysilicon production in India.

Production constraints

A competitive polysilicon plant requires investments running into billions of dollars and very large production volumes to remain viable. Chinese firms built this scale over more than a decade. For India, because there is no existing ecosystem, costs could be even higher due to imported equipment and infrastructure requirements.

High capital costs and limited competitiveness weaken the investment case: Capital costs of establishing a polysilicon plant are significant, with large-scale plants with annual capacities of 100,000 tonnes typically involving CapEx of US $1–1.2 billion.[15] A 100,000-tonne output would translate to roughly 40 GW of module manufacturing, based on 2.5 grams of polysilicon required per watt of module generation capacity. Newer production technologies, however, are reducing this requirement to around 1.7–2 grams per watt, owing to thinner cells and more efficient production.[16,17]

In April 2026, polysilicon spot prices in China were around US $4–6 per kg, compared to significantly higher prices of approximately US $18–19 per kg outside China.[18] In India, prices of polysilicon are projected to be around US $17–18 per kg.[19]

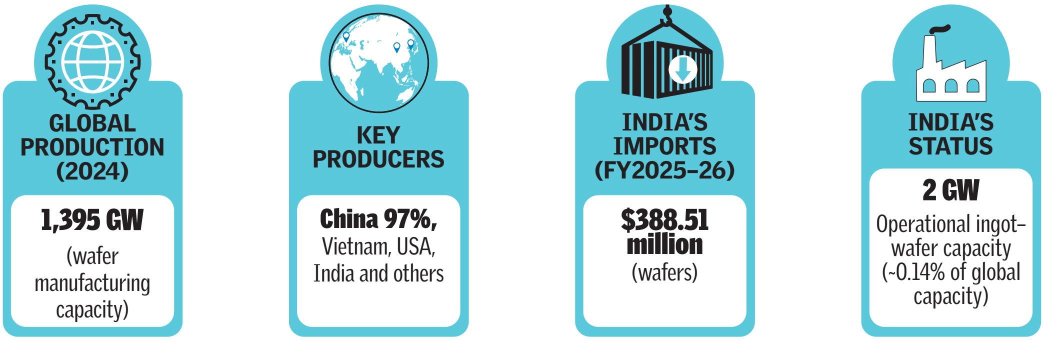
Even at larger production scales, production costs in India would remain substantially above prevailing Chinese prices. The combination of high capital intensity, lower economies of scale and higher energy costs makes it difficult for new Indian producers to compete purely on cost.

Commercial viability depends on downstream manufacturing scale: Polysilicon production would require a very large and continuous demand to operate efficiently. A commercially viable production facility would require 40,000–50,000 tonnes of capacity. With very limited capacities downstream in wafer and cell production (*later sections*), firms contemplating polysilicon production would be compelled to build capacities significantly larger than their immediate downstream requirements in anticipation of future demand.

Technology dependence remains an additional barrier: India has no commercial-scale polysilicon manufacturing base, requiring firms to import specialized production equipment and to rely on foreign technical expertise for plant commissioning and operation.

3. Wafers

Figure 4: Wafers: India's position in the global value chain



Source: CSE (compiled from various sources)

Technology landscape

While less chemically intensive than polysilicon manufacturing, converting silicon ingots into wafers is a more complex process than downstream stages such as module assembly. The Czochralski process converts polysilicon into monocrystalline ingots. Multicrystalline ingots, though less relevant today, with monocrystalline wafers increasing their share from 45 per cent in 2018 to nearly 99 per cent today, are produced by casting methods.[20]

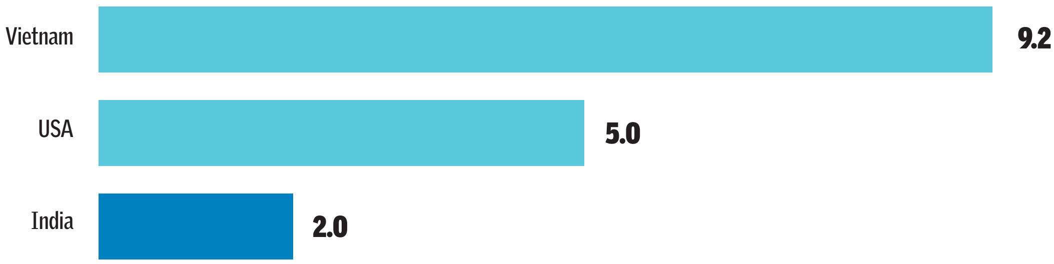
These ingots are then sliced into thin wafers using high-precision techniques. Wafer thickness has steadily declined over time to reduce material consumption and costs, typically reaching around 130–150 microns today.

Nearly 85 per cent of wafer manufacturing costs are attributable to the raw material, polysilicon. Wafer cutting accounts for around 5 per cent, while electricity costs make up approximately 2 per cent.[21]

Production geography

Global silicon wafer production capacity is even more concentrated than polysilicon, with China accounting for 97 per cent of the global total production of 804 GW at the end of 2024. China reached 680 GW of wafer production in 2025. Overall production capacity stood at 1,395 GW per annum at the end of 2024, of which China accounted for 1,349 GW. [22,23]

Graph 1: Global solar wafer manufacturing capacity: leading producers outside China (GW/year)



Source: Compiled by CSE

Vietnam has 9.2 GW, the US 5 GW, and India 2 GW of ingot–wafer production capacity as of April 2026.[24,25,26,27,28]

The European Union has yet to build commercial-scale wafer production.[29] The US is adding another 3.3 GW.

Recent announcements in India aim to develop about 100 GW of ingot-wafer manufacturing capacity (see *Annexure III*).

There is also a push to locate manufacturing units in West Asia and North Africa to circumvent US tariffs on solar imports from China, South Asia and Southeast Asia.[30] For instance, TCL Zhonghuan is reportedly building a 20-GW wafer factory in Saudi Arabia.[31]

Trade landscape in India

In 2023–24, China supplied roughly 7.7 GW of solar wafers to India, equivalent to around 811 million units, at a unit cost of about US $0.44. This increased significantly to 38.03 GW in 2025–26, with 2,754 million units, at a unit cost of about US $0.17.[32]

Production constraints

Upstream capital intensity is markedly higher than in module assembly. Establishing a 1-GW ingot-wafer facility in India is estimated to require around Rs 700 crore against roughly Rs 170 crore per GW for module assembly (see *Figure 1*).

Equipment and technology dependence raise costs and lead time. Wafer manufacturing requires precision slicing equipment and advanced crystal-growth

Table 3: India's silicon wafer imports and exports between 2021–22 and 2025–26[33]

Import (a)

Financial year	Import value (US$ million) (HS: 38180010)	Import quantity (tonnes)	Countries
2021–22	153.73	4,768	China (99.2%), Hong Kong (0.5%)
2022–23	195.35	3,924	China (98.8%), Hong Kong (0.6%)
2023–24	330.75	11,211	China (95%), Hong Kong (4.8%)
2024–25	156.55	12,680	China (96.8%), Hong Kong (2.2%)
2025–26	388.51	32,000	China (98.4%), Thailand (1.1%)

Export (b)*

Financial year	Export value (US$ million) (HS: 38180010)	Export quantity (tonnes)	Countries
2021–22	0	0.063	Russia (46%), Bhutan (44%)
2022–23	0.06	2.6	China (84.8%), Bhutan (15.1%)
2023–24	0.12	1.9	Germany (58%), Bhutan (24.6%)
2024–25	0.08	19.1	China (96%), Germany (3.8%)
2025–26	0.61	219	China (98.4%), Hong Kong (1.6%)

*The data could include reexports, lower-grade or non-solar wafers, processing-related shipments, or other transactions recorded under the broad customs classification. The export figures should be treated with caution as it is unlikely that the exports originate from India's domestic wafer production capacity. The relevant HS code covers 'undiffused silicon wafers', and does not by itself establish where the wafers were manufactured or whether they were produced from domestically manufactured polysilicon.

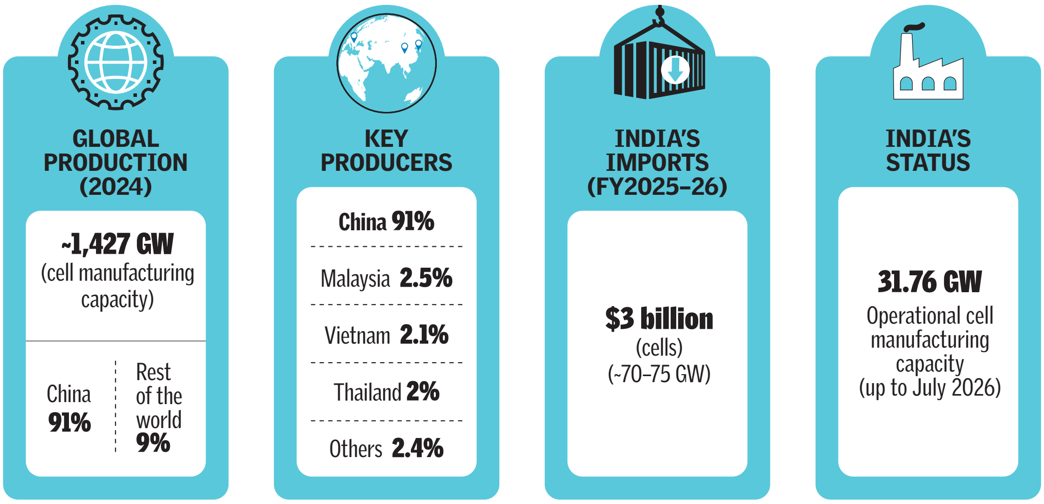
technology, which reflect decades of sustained R&D investment and are currently unavailable indigenously. Importing this machinery and potentially polysilicon feedstock adds to costs and delays the operationalization of production facilities. Also, the commissioning lead time for such plants is relatively long (between eight and 20 months).[34] This causes costs to accumulate well before commissioning.

The skills base for upstream manufacturing remains thin. Firms report shortages of technical personnel in the relatively technology-intensive upstream segments. Companies are absorbing the cost of in-house training, and Indian manufacturers also have to send engineers to China for training in wafer and cell production processes.[35]

Process control requirements are demanding. Small deviations in ingot-growth conditions can introduce crystal defects that could cause failures and degrade downstream cell performance, making process control a persistent operational challenge for new entrants.

4. Cell

Figure 5: Cells: India's position in the global value chain



Source: CSE (compiled from various sources)

Technology landscape

Cell manufacturing is the central value-add stage in the solar PV value chain, converting wafers into electricity-generating devices and determining module efficiency and cost. The segment is technologically diverse and continues to see active incremental gains in technique, efficiency and material use. Among the most widespread technologies:

- Passivated Emitter and Rear Contact (PERC), which dominated the market until 2023, accounted for roughly 20 per cent of global production in 2024.[36]

- However, Tunnel Oxide Passivated Contact (TOPCon) has scaled to over 70 per cent, becoming the leading technology. PERC is projected to be phased out by around 2030. TOPCon can be implemented by upgrading existing PERC production lines, avoiding full capital replacement.

Commercial efficiencies have reached about 21.7 per cent for PERC and 23.2–23.6 per cent for TOPCon and other n-type technologies, with projections of up to 26 per cent over the next decade.

Besides crystalline silicon (c-Si), silver and aluminium are among the most important and expensive materials used in cell manufacturing. As of 2024,

Graph 2: Cost share of manufacturing TOPCon cells based on Chinese manufacturing trends[37]

Source: CSE; data source: SolarZoom

existing processes required around 70 mg of silver per cell for p-type PERC cells (M10 wafer) and around 110 mg per cell for n-type TOPCon cells. This is expected to decline as material efficiency improves. These figures correspond to roughly 9 mg/W and 13 mg/W, respectively.[38]

Production geography

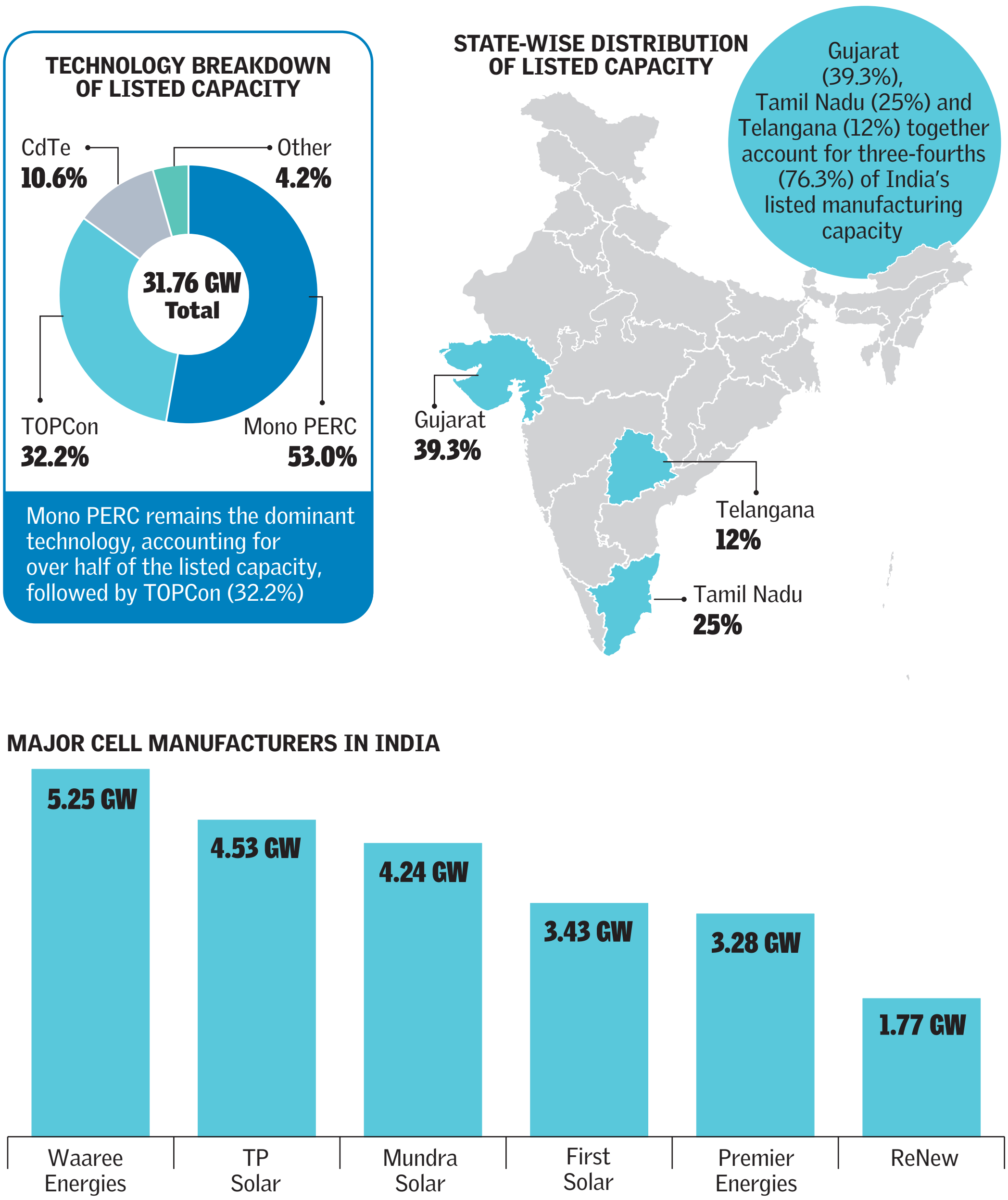
China's PV cell production output stood at 695 GW in 2024 and 660 GW in 2025. With global cell production capacity reaching 1,427 GW, China accounted for 1,303 GW in 2024, representing about 91.3 per cent of the global total. Other major producing countries include Malaysia, Vietnam, South Korea and India.[39] Leading world manufacturers include Tongwei (one-tenth of the world total), JinkoSolar, JA Solar, LONGi and Trina Solar—all Chinese companies.

India's domestic cell manufacturing capacity has expanded rapidly in recent years, with the Approved List of Models and Manufacturers (ALMM) for solar PV Cells reporting around 31 GW of capacity as of July 2026 (see *Annexure I*), equivalent to roughly 1.5–2 per cent of global manufacturing capacity.

Trade landscape in India

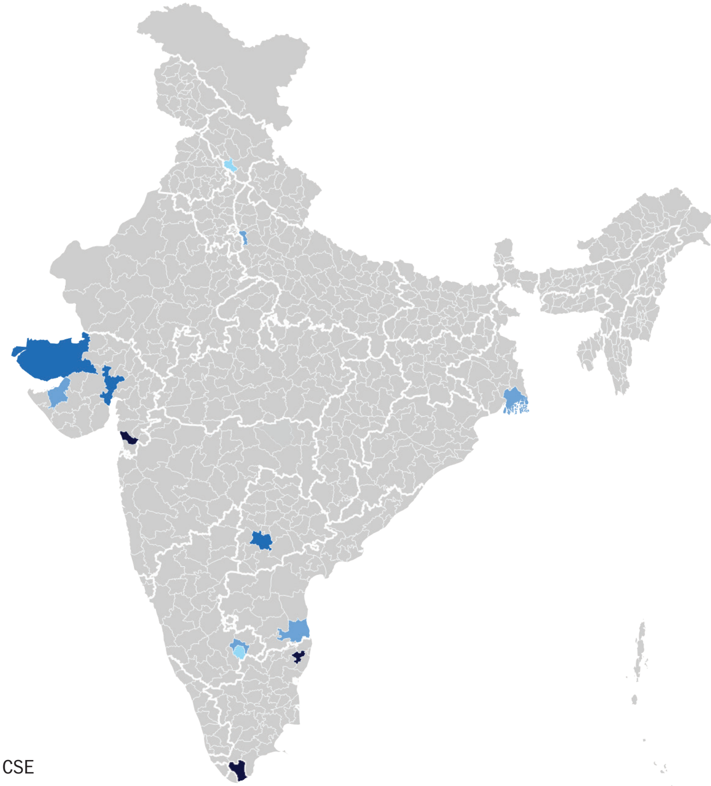
India imported 33.3 GW of solar cells from China in 2024–25 at a unit cost of roughly US $0.042/W. This increased to 45.3 GW in 2025–26, with the unit cost remaining broadly unchanged. In FY 2025–26, India accounted for 33.7 per cent of the total value of Chinese solar cell exports, followed by Indonesia at around 27 per cent. However, Indonesia's share exceeded India's in the first quarter of 2026.

Figure 6: India's solar cell manufacturing landscape



Source: CSE; compiled from ALMM-II (July 2026)

Map 1: ALMM-II listed solar cell manufacturing in India (see *Annexure I)*



Source: Government of India, CSE

Table 4: India's silicon cell imports and export between 2021–22 and 2025–26[40]

Import (a)

Financial year	Import value (US$ million) (HS: 85414011, 85414200)	Import quantity (number in million)	Countries
2021–22	1,137.86	773.4	China (94%), Malaysia (2.5%), Thailand (1.5%)
2022–23	1,310.30	1,233.8	China (44%), Thailand (20%), Vietnam (18%), Malaysia (13%)
2023–24	1,853.05	2,691.9	China (56%), Malaysia (17%), Thailand (13%)
2024–25	1,641.25	5,061.5	China (83%), Thailand (7%), Indonesia (4%)
2025–26	3,058	8,010.3	China (61%), Indonesia (15%), Thailand (8.6%)

Export (b)

Financial year	Export value (US$ million) (HS: 85414011, 85414200)	Export quantity (number in million)	Countries
2021–22	28.96	0.835	US (65.8%), Nigeria (7.5%), Afghanistan (3.5%)
2022–23	1.12	1.85	China (49%), Malaysia (12.5%), Congo (7%)
2023–24	54.67	45.16	US (59.4%), Thailand (22.5%)
2024–25	32.03	38.9	US (93%), Canada (5.5%), Thailand (1.5%)
2025–26	20.24	45.7	US (47%), UAE (41.8%), China (9%)

Production constraints

The capital cost of setting up a manufacturing plant could be Rs 650–850 crore per gigawatt. Industrial estimates indicate that the cost of cell manufacturing machinery is at least three to four times the cost of module manufacturing. In India, the cost of machinery for cell manufacturing is around Rs 250–300 crore/GW. This makes up ~ 35–45 per cent of the total project cost.

Technology transitions shorten investment cycles. The industry is rapidly transforming from PERC to TOPCon, while HJT, back-contact, and tandem-cell technologies are entering commercial deployment. Installations today risk becoming obsolete within a few years. This not only raises investment risk but also raises entry barriers for smaller firms.

Technology dependence extends beyond manufacturing equipment. Much of the intellectual property underlying high-efficiency cell manufacturing remains concentrated among Chinese, European and Japanese firms. India imports not just equipment; it also imports know-how, commissioning support, and other services, limiting its ability to independently improve manufacturing efficiency or rapidly adopt next-generation technologies.

5. Module

Technology landscape

The final stage of solar manufacturing is where solar cells are assembled into commercially deployable modules. This stage is relatively less technologically complex than upstream manufacturing stages, with lower entry barriers, and involves interconnecting solar cells and encapsulating them within glass, polymer encapsulants, and frames. Competitiveness at this stage is determined by factors such as production scale, automation, quality consistency, and compatibility with evolving cell technologies and wafer formats. Although this is the least technologically intensive stage of the value chain, it remains highly dynamic due to the need to continuously adapt to changes in upstream technologies.

BUILDING TECHNOLOGY CAPABILITY

The most technologically sophisticated segment of the value chain, solar cells, is also the most intellectual-property-intensive, with China, the United States, Japan and South Korea accounting for the overwhelming majority of global solar patents, while Indian patenting remains limited and is dominated by foreign firms. This reflects a wider capability gap in process innovation, cell architecture and manufacturing know-how, which cannot be bridged by capacity expansion alone.

Technology acquisition for India, therefore, is an important complement to domestic R&D. Technology acquisition could happen in the following different ways:

- Importing intermediate and capital goods;
- Movement of capital and knowledge through Foreign Direct Investment, including joint ventures;
- Licensing technologies (intellectual property rights); and
- Movement of people.

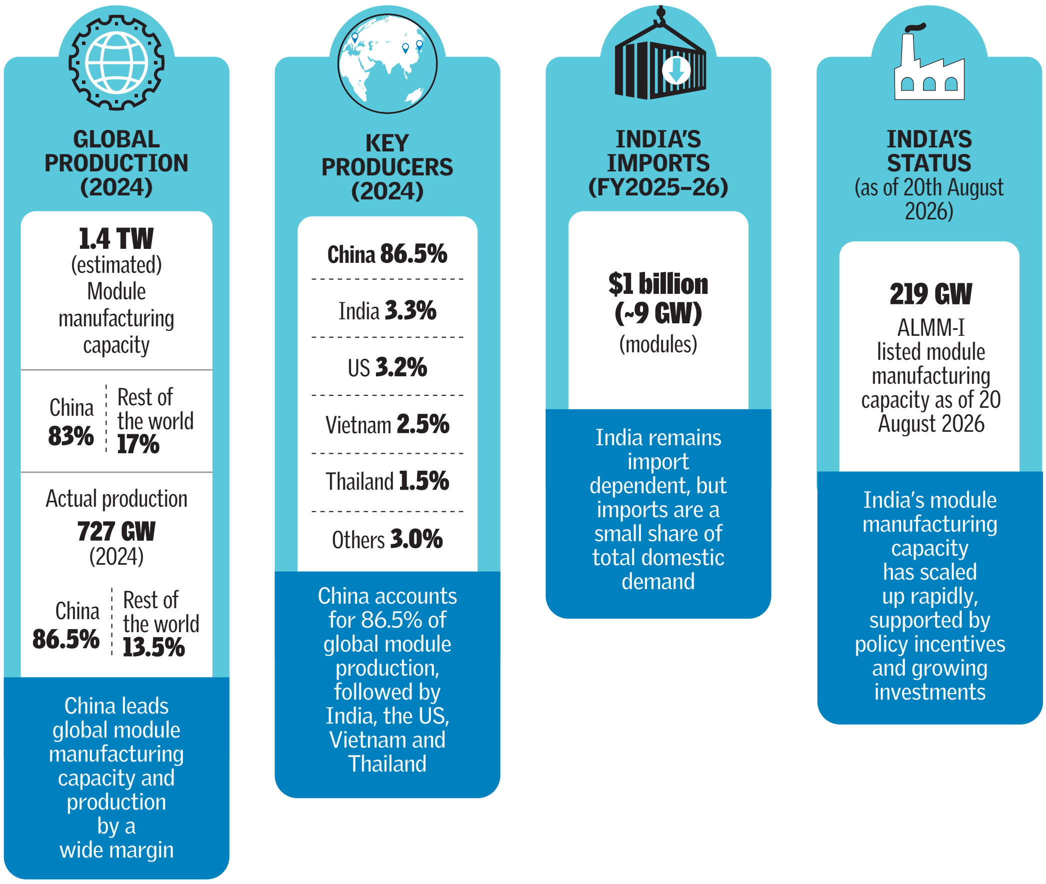
Table 5: Recent examples of technology acquisition in India's solar manufacturing

Indian manufacturers have relied on a combination of equipment imports, joint ventures, acquisitions, licensing arrangements and technical collaborations to build capabilities in solar manufacturing.

Example	Import of equipment/capital goods	FDI/joint venture	Licensing/IP acquisition	Movement of people/ training
Premier Energies + Sino-American Silicon Products (Taiwan) (2025)	√ (Wafer technology and equipment)	√ Main acqusition route	√ Possibly through the joint venture	
Reliance acquisition of REC Solar (2021)	√	√ Main acqusition route	√ Acquisition of 600+ patents and HJT IP	√ Some knowledge transfer through integration
Waaree acquisition of Swiss HJT technology company Meyer Burger assets	√	√ Main acqusition route	√ Acquisition of HJT manufacturing IP	
Emmvee TOPCon line (RENA, Centrotherm, Halm)	√ Main acqusition route (equipment imports)	X	√ Possibly some process know-how	√ Training, technical support, spare parts
ISC Konstanz collaborations (Adani, Solex, others)	√ Possible acquisition through partnership	X	√ Main acqusition route (technology transfer, process know-how)	√ Main acqusition route (workshops, engineers, R&D collaboration)

Source: CSE (compiled from various sources)

Figure 7: Modules: India's position in the global value chain



Source: CSE (compiled from various sources)

Table 6: TOPCon module market price comparison between countries (US$/W)

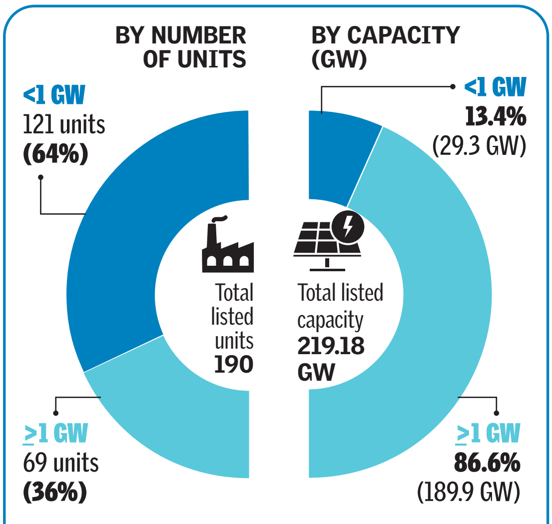
Source	Module	China	India	India (with domestic cell)	US
OPIS (Dow Jones) (mid-2026) ($/W; respective market basis)	TOPCon	0.104–0.119 (FOB)	0.15 (EXW)	0.26–0.27 (EXW)	0.26–0.33 (DDP)
Infolink (mid-2026)	TOPCon	0.114 (FOB)	0.145 (FOB)		0.31 (FOB)

Note: FOB: Free on Board; EXW: Ex Works; DDP: Dellivery Duty Paid

Source: CSE, OPIS, Infolink, PV Magazine

Figure 8: Analysis of ALMM-I listed capacity (as of August 2026)

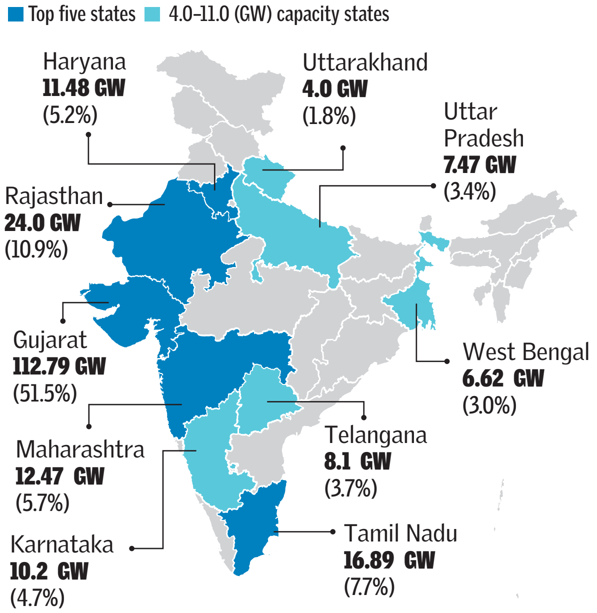
Total 190 units spread across 19 states with a capacity of 219.18 GW

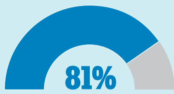


Median unit size	Mean unit size	Largest listed unit	States represented
512.5 MW	1.15 GW	16.44 GW	19

64% of units are small (<1 GW) but contribute only **13% of total capacity**

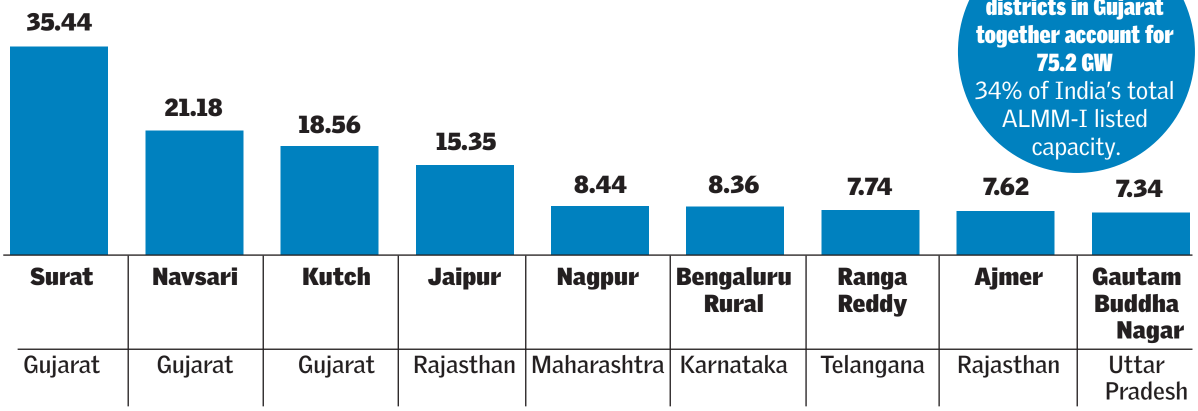
TOTAL ALMM-I LISTED CAPACITY: 219.18 GW





of total ALMM-I listed capacity contributed by top five states

TOP DISTRICT-LEVEL CONCENTRATIONS OF ALMM-I LISTED MODULE CAPACITY (GW)



Top three districts in Gujarat together account for 75.2 GW
34% of India's total ALMM-I listed capacity.

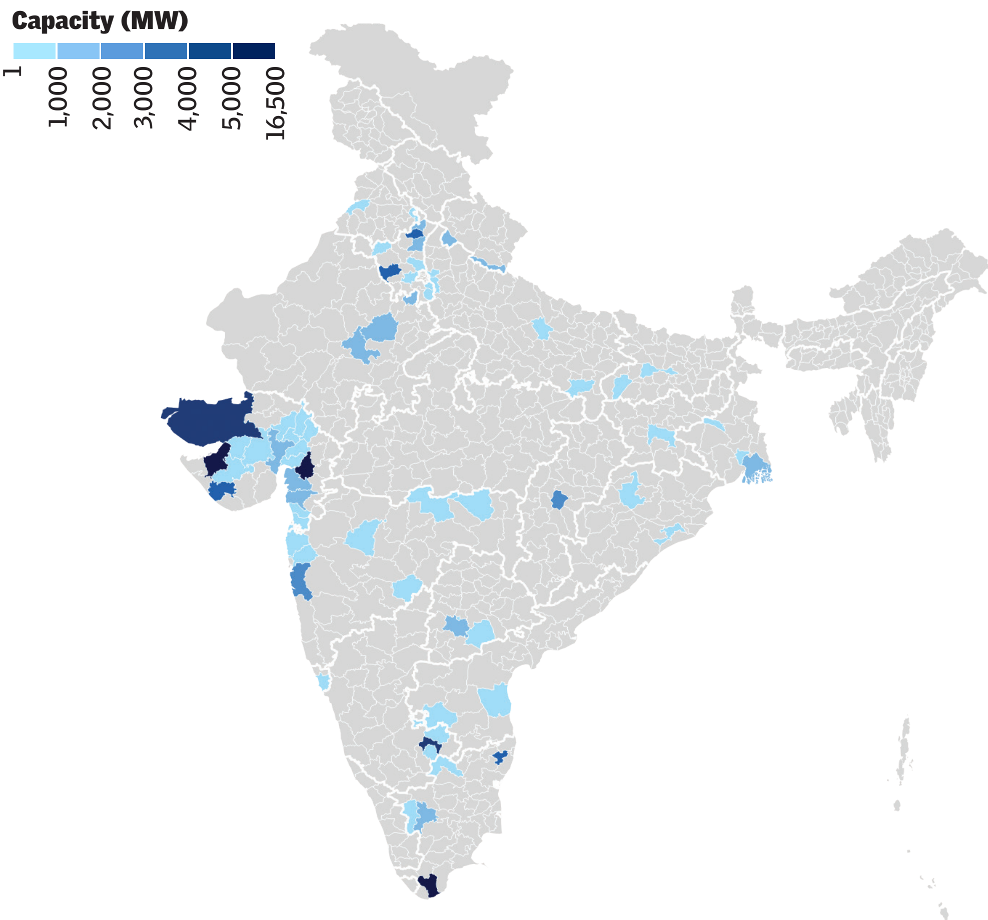
Source: CSE (from ALMM-I notification)

Production geography

China possessed over 83 per cent of global solar module manufacturing capacity by the end of 2024, with total global module manufacturing capacity estimated at more than 1.4 TW.[41] Five Chinese companies alone had a combined module manufacturing capacity of around 525 GW in 2026.

As of May 2026, India’s ALMM-I-listed solar module manufacturing capacity exceeds 219 GW. More than half of this capacity is concentrated in Gujarat, with the Surat–Navsari belt alone hosting over 60 GW. Other major manufacturing hubs include Rajasthan, Tamil Nadu, Maharashtra, Karnataka and the Delhi-NCR region.

Map 2: ALMM-I registered solar PV module manufacturing capacity



Source: Government of India, CSE

Trade landscape in India

Table 7: India's solar PV module import and export in 2021–22 to 2025–26[42]

Import (a)

Financial year	Import value (US$ million) (HS: 85414012, 85414300)	Import quantity (number in million)	Countries
2021–22	3,363.21	100	China (91.4%), Hong Kong (7%), Malaysia (1%)
2022–23	943.52	7.9	China (92.73%), Vietnam (4.2%), Singapore (2.6%)
2023–24	4,353.51	48.5	China (65.48%), Vietnam (21.48%), Malaysia (5.5%)
2024–25	2,151.75	41	China (78.85%), Vietnam (15.50%), Hong Kong (3.86%)
2025–26	994.66	33.5	China (51.27%), Vietnam (29.80%), Malaysia (11.3%)

Export (b)

Financial year	Export value (US$ million) (HS: 85414012, 85414300)	Export quantity (number in million)	Countries
2021–22	83.5	.967	US (72.7%), Somalia (9.3%), South Africa (5.4%)
2022–23	1,031	5.75	US (97%), UAE (.55%), Turkey (0.35%)
2023–24	1,969	11.2	US (98.5%), Somalia (0.5%)
2024–25	1,120.75	7.5	US (97.2%), Bangladesh (1.8%)
2025–26	1,051.3	7.6	US (97%), Bangladesh (1.8%)

Production constraints

For solar modules, the technology is relatively mature and widely available. The constraints are mostly economic, supply-chain-related and structural.

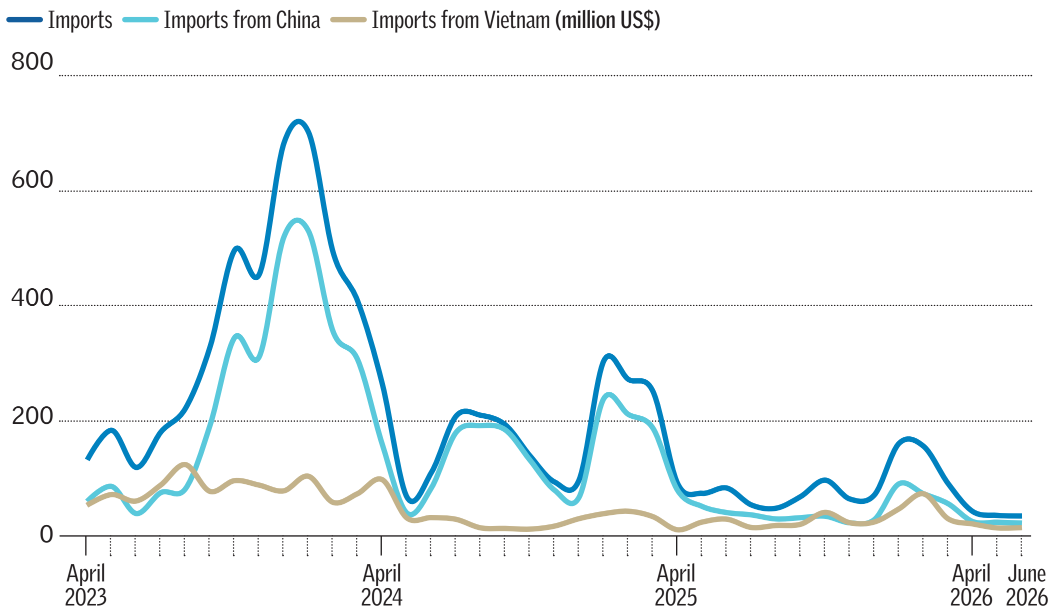
Indian-manufactured modules (non-DCR) remain more expensive than their Chinese counterparts, with prices roughly 25–35 per cent higher for TOPCon in mid-2026 (see *Table 6: TOPCon module market price comparison between countries*).

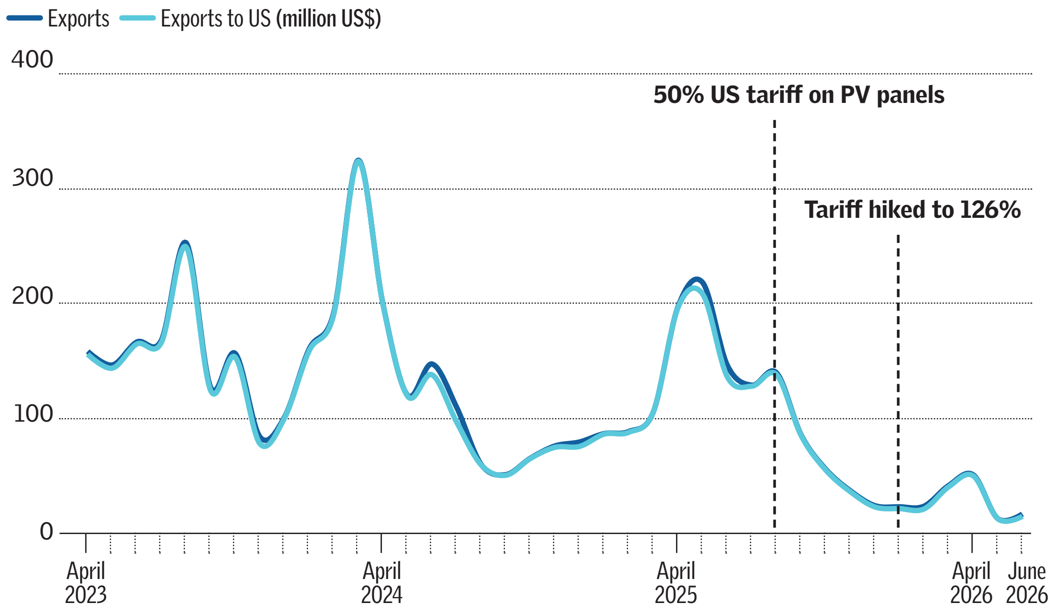
The price differential reflects higher upstream input and manufacturing costs in India, including duties on imported cells, as well as differences in scale, supply-chain integration and capital costs.

This price gap, however, almost closes when we account for the duties on Chinese modules imported into India.

Graph 3: India's monthly trade in solar PV modules by value (million US$)

India's solar PV module imports and exports have both moderated over the past three years, although import values fluctuated considerably during the period.





Source: DGFT

WHY ARE VIETNAM-MADE MODULES COMPETITIVELY CHEAP?

Vietnam's cost advantage rests on supply-chain positioning and manufacturing efficiency. Many of the country's major solar manufacturers are Chinese-owned or operated, bringing established technology, manufacturing know-how and supply-chain relationships. Trina Solar, for example, operates a facility in Thai Nguyen with annual capacities of 6.5 GW of wafers, 4 GW of cells and 5 GW of modules.[43]

Combined with competitive industrial electricity tariffs, lower labour costs and an export-oriented incentive regime, this enables Vietnam to produce modules at lower rates. IRENA estimates that a fully domestic TOPCon module produced in Vietnam costs around US $0.18/Wp, compared with US $0.191/Wp in India. The cost advantage becomes even larger when Chinese upstream inputs are used: importing Chinese polysilicon, wafers and cells reduces Vietnamese module costs by approximately 7 per cent, 19 per cent and up to 31 per cent, respectively.[44] India's effort to localize cells and upstream components, by contrast, increases production costs during the transition because domestic upstream capacity remains more expensive and constrained.

Vietnam, meanwhile, has emerged as the lowest-cost location for fully domestic solar PV manufacturing outside China: IRENA estimates the cost of producing a fully integrated TOPCon module in Vietnam at $0.18/W, compared with $0.191/W in India (see *Graph 4: Total TOPCon module manufacturing cost under different import-dependence scenarios*).

Note: Data in Table 6 represent market prices reported by market intelligence sources, whereas Graph 4 presents manufacturing costs modelled by IRENA. The two measures are therefore not to be confused.

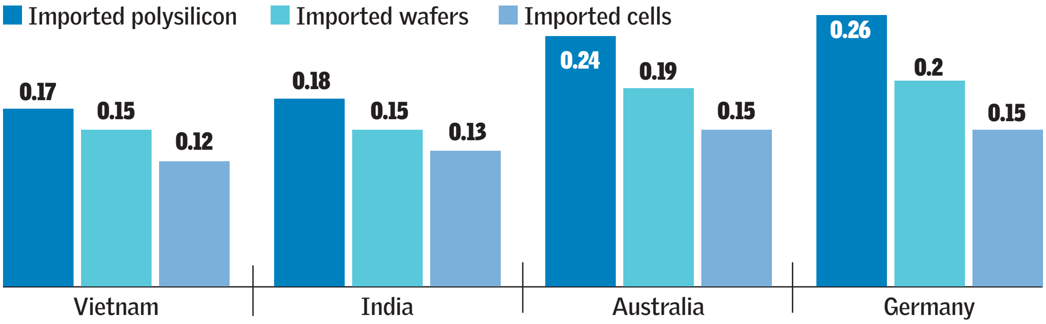
The domestic component ecosystem remains incomplete. Solar glass, backsheets, encapsulants, junction boxes, aluminium frames and especially metallization paste continue to rely either partially or substantially on imports. Consequently, module manufacturers remain exposed to external factors (see *Beyond modules: component dependencies*).

Global overcapacity, with capacity exceeding annual demand, compresses margins. This structural challenge has driven module prices to extremely competitive levels, leaving manufacturers operating on extremely thin margins. New entrants face the challenge of recovering capital investment in a constricted environment. Making money from module manufacturing thus becomes difficult.

Value capture in module assembly remains inherently limited as it represents the lowest value-added segment of the crystalline silicon value chain. Although it generates employment and contributes to domestic manufacturing capacity, much of the technological sophistication, intellectual property and manufacturing value remain concentrated upstream in polysilicon, wafers and cells.

Graph 4: Total TOPCon module manufacturing cost under different import-dependence scenarios ($/Wp)

Module costs decline significantly when upstream components are imported from China rather than manufactured domestically. Vietnam and India remain the low-cost manufacturing locations across all scenarios, while Australia and Germany face substantially higher production costs.



Source: IRENA 2026,[45] graph: CSE

Frequent technology transitions require continual investment. Although module assembly is less technologically intensive than cell manufacturing, manufacturers must continuously adapt production lines to accommodate changing cell technologies, wafer sizes and module architectures. As newer technologies such as back-contact and tandem modules enter commercial production, manufacturers will need further investments despite relatively short equipment depreciation cycles.

Cross-cutting analysis

The expansion of domestic manufacturing capacity, particularly in cells and modules, has been accompanied by a change in the composition of imports. Rather than simply reducing imports across the value chain, India's manufacturing expansion appears to be changing what it imports: module imports have moderated, while imports of cells and wafers have increased.

Graph 5 shows the evolution of India's quarterly imports of solar modules, cells and wafers. Module imports have generally declined, while cell and wafer imports have increased in recent periods. This is consistent with the rapid expansion of India's domestic module manufacturing base.

A decline in module imports does not necessarily imply a proportional reduction in external dependence. Some import dependence may simply have shifted one stage upstream in the value chain. A domestically assembled module can therefore reduce imports of finished modules while still embodying substantial imported value through cells, wafers, polysilicon and other components.

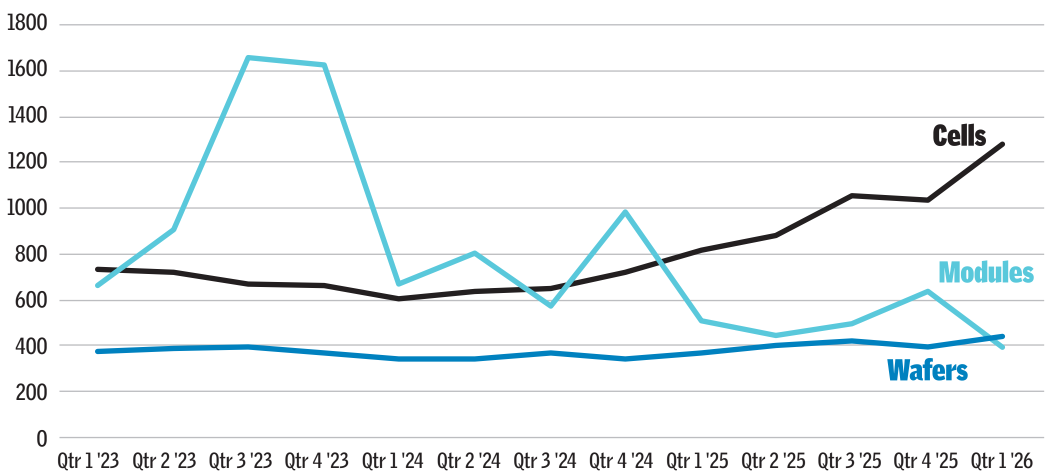
Figure 9: Status of solar manufacturing in India

STAGE	Raw materials (quartz)	Polysilicon	Ingot/ wafer	Cell	Module	Components (BoM)
INDIA'S CAPACITY (AS OF AUGUST 2026)	• High-purity quartz reserves • Key states: Rajasthan **(55%)**, Telangana (**28%)**, others **(17%)**	**0 GW** No commercial production	**2 GW** (~0.1% of global) One ingot and wafer facility commissioned	**31.76 GW** Listed capacity (ALMM-II)	**219.18 GW** Listed capacity (ALMM-I)	**Glass 15–18 GW;** Aluminium frames emerging; Others limited
GLOBAL PICTURE (2024)		China 93.5% of global polysilicon production (~3.25 million tonnes capacity)	China 97% of global wafer manufacturing capacity	China 91.3% of global cell manufacturing capacity	China 83.4% of global module manufacturing capacity	China 80–90% dominant in key BoM (glass, EVA, backsheet, aluminium frames, junction boxes)
INDIA'S POSITION (2026)	Resource-rich, processing-poor	Absent	Nascent	Nascent	Established	Emerging

Source: Compiled by CSE

Graph 5: India's quarterly import of solar modules, cells and wafers (million US$)

Imports of modules have generally declined, while import of cells and wafers have slightly registered an uptick



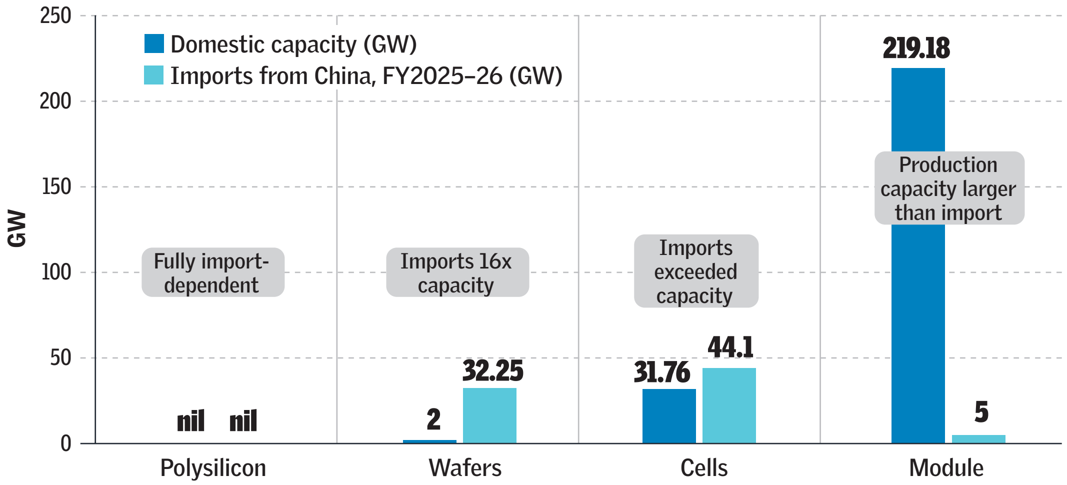
Source: DGFT

The pattern is particularly visible in wafers. China supplied around 38 GW of wafers to India in FY2025–26, a substantial increase from approximately 7.7 GW in FY2023–24.

The rapid increase in domestic manufacturing capacity is nevertheless an important change in India's position in the global solar value chain. India now has substantial capacity in both cells and modules, alongside the emergence of ingot-wafer manufacturing. However, capacity figures should not be interpreted as equivalent to actual domestic production.

This distinction becomes particularly important in interpreting *Graph 6*, which compares India's domestic manufacturing capacity with imports from China across the solar value chain.

Graph 6: Where India still depends on China: capacity vs imports, by stage

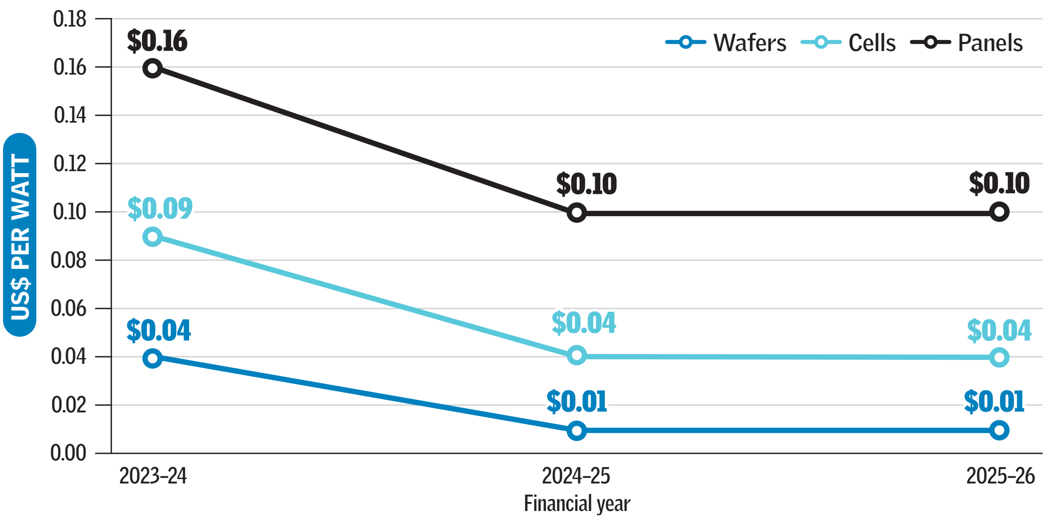


Note: The domestic capacity figures represent capacity available as of August 2026, whereas the import figures relate to FY2025–26.

- The two datasets therefore do not correspond to the same period. In addition, the comparison is not strictly like-for-like: it compares domestic manufacturing capacity with imports, rather than domestic production with imports.
- Capacity represents the potential output of manufacturing facilities, but does not indicate actual production, utilization rates or the extent to which facilities were operational during FY2025–26.
- The graph should therefore not be interpreted as a direct measure of whether domestic capacity is sufficient to replace imports.
- Instead, it provides an indication of the relative scale of India's emerging manufacturing base and the continuing scale of Chinese supply to the Indian market.
- The import figures shown for China are calculated based on Ember's China solar export data.
- They capture India's imports from China, rather than India's total imports from all countries.

Source: DGFT, Ember, ALMM Notification; compiled by CSE

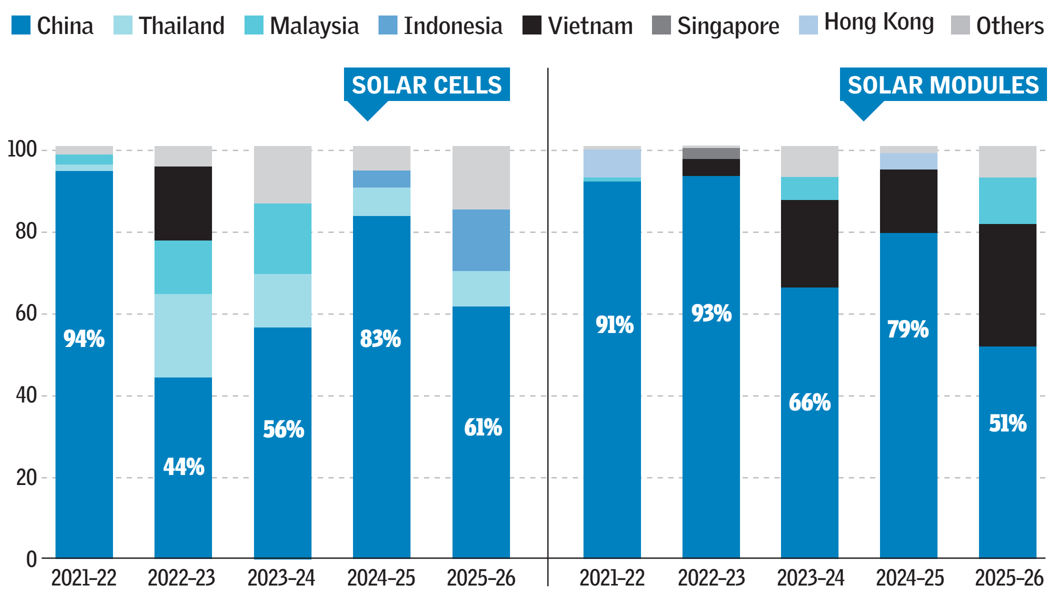
Graph 7: Comparative cost analysis (average cost per watt) of India's solar imports from China (US$/watt)



Source: Ember, CSE

Graph 8: Duties on China have redirected import dependence: Source-country share of India's imports by value

Anti-dumping duties of 23–30 per cent on Chinese cells and modules; BCD 40 per cent (2022), then 20 per cent + AIDC (2025)



Source: DGFT, graph: CSE

Beyond modules: Component dependencies

A module's finished-product economics depends on the four core value-chain stages of polysilicon, wafers, cells and modules. However, a cluster of smaller, non-silicon inputs—metallization paste, solar glass, backsheets and encapsulants, aluminium frames and junction boxes—together account for a meaningful share of module cost; metal inputs (silver paste and aluminium) alone can account for up to 42 per cent of the non-silicon cost of an advanced cell.[46]

This section reviews India's standing as of July 2026 across four of these components.

A note on data: Component-level trade data are approximate because most solar inputs do not have dedicated HS codes and are grouped with non-solar products. The most reliable component-level estimates come from DGTR trade-remedy investigations, which define products more narrowly and report import volumes, prices and domestic demand. Company disclosures provide a second useful source.

Metallization paste

Metallization paste, the silver-based conductive paste screen-printed onto a cell to form its front and rear electrical contacts, is one of the highest-value non-silicon inputs in cell manufacturing and one of the most geographically concentrated. China accounts for roughly 90–92 per cent of global PV silver paste production, and the top three producers worldwide, which are all Chinese-owned, together hold close to 70 per cent of the market.[47] Metallization paste remains almost entirely import-dependent in India, with near-net-zero domestic silver paste production.[48]

Challenges that explain this gap:

- Price sensitivity: Cell manufacturing is highly sensitive to fluctuations in silver and copper prices. Given this volatility and the inability to scale in potential Indian units, Chinese imports remain the preferred source.[49]

- Technology lock-in: India's solar cell manufacturing relies on Chinese production technology that is optimized for Chinese silver paste, making it difficult for domestically developed pastes to be adopted without access to Chinese intellectual property.[50]

- A moving technology target: India's solar industry is migrating from older P-type mono-PERC cells to higher-efficiency N-type TOPCon cells, which

Table 8: India's imports of silver metallization paste and major suppliers (FY2025–26)

Imports under the relevant HS category indicate India's dependence on imported silver metallization paste, with China accounting for around two-thirds of import value and Chinese-owned firms dominating global supply

Parameter	Detail
HS code category	'All other semi-manufactured forms of silver'
Gross imports	US $184.33 million (+64.51% y-o-y)
Imports from China	US $120.43 million (approx. 65% of total)
Major global suppliers to India	Heraeus (Haitian PV, China) and Solamet (DKEM, China)

Source: DGFT, compiled from other sources

need more refined silver pastes, a shifting specification that is hard for an infant domestic industry to track.[51]

- An upstream input gap: Silver paste itself requires refined powdered silver, which India almost entirely imports. Cost dynamics have never allowed a domestic refined-silver producer to develop, so even a domestic paste industry would depend on imported feedstock and struggle to match Chinese manufacturers' subsidized access to it.

A broadly similar China-dominated pattern applies across most of the components discussed in this section.

There is, however, a demand-side opening. As India's cell-manufacturing capacity scales up from what was until recently a small base, silver paste demand is expected to grow with it—around 20 per cent of India's annual silver demand is projected to be accrued to solar-cell paste by 2030.[52]

Whether this translates into domestic capacity will depend on whether India can also diversify its import-source countries in parallel, which does not yet appear to be happening: the HS code covering silver pastes recorded gross imports of US $184.33 million in FY 2025–26, up 64.51 per cent year-on-year on the back of PV cell capacity expansion, of which US $120.43 million (about 65 per cent) came from China alone.[53] Heraeus (whose silver-paste segment was acquired by Haitian Photovoltaic, China) and Solamet (now DKEM, China) have been the major suppliers to India.

Solar glass

Solar glass is the heaviest component of a conventional solar module by weight, and global production remains highly concentrated in China. India's domestic manufacturing base remains limited, with Borosil Renewables accounting for the majority of installed capacity and Vishakha emerging as the second domestic producer. Indian manufacturers face intense competition from Chinese producers, both through direct imports and through manufacturing facilities in countries such as Indonesia, Malaysia and Vietnam, which supply solar glass at highly competitive prices. To support domestic manufacturing, India imposed anti-dumping duties on Chinese and Vietnamese solar glass in 2019, which were extended in 2024 for another five years. Another set of import restrictions on imports from Malaysia and Indonesia was in effect between 2021 and 2026 and has been further extended until 2031.[54,55]

In India solar glass manufacturing capacity rests at 15–18 GW, with another 20–22GW in pipeline. [56,57]

Backsheets and encapsulants

Backsheets and encapsulants form the protective polymer layers that shield solar cells from moisture, mechanical stress and environmental degradation, making them essential to module durability and performance. India has developed a modest domestic manufacturing base for these components, particularly for conventional PET-based backsheets and EVA (ethylene-vinyl acetate) encapsulants. However, production of higher-value materials remains limited. Advanced fluoropolymer-based backsheets (PVF/PVDF) continue to rely on imported raw materials, while POE-based encapsulants, increasingly required for high-efficiency N-type technologies such as TOPCon, are almost entirely import-dependent.[58] The upstream specialty polymers used in these products are sourced primarily from a small number of international suppliers, exposing manufacturers to supply chain and pricing risks.

As India's module manufacturing shifts towards newer cell technologies, demand for these advanced materials is expected to increase. India's Directorate General of Trade Remedies (DGTR) started an anti-dumping investigation on solar encapsulants (excluding EVA encapsulants) from China in September 2025. It also initiated an anti-dumping investigation into solar encapsulants from South Korea, Thailand and Vietnam.

Major domestic backsheet manufacturers include RenewSys, Knack Energy, NovaNext, Vishakha Renewables and Polycom Associates, while encapsulant manufacturing is led by RenewSys, with Knack Energy and Vishakha Renewables also having established production capacity. [59,60]

Aluminium frames

India remains heavily dependent on imports for aluminium frames, with industry reports suggesting that around 95 per cent of current requirements are imported. At the same time, aluminium frames are among the few solar components for which India has begun establishing domestic manufacturing capacity. The sector's competitiveness challenge is reflected in the government's 2024 anti-dumping investigation into anodized aluminium frames from China. DGTR found that Chinese imports had increased substantially even after domestic commercial production began in 2021–22, while significant domestic capacity remained underutilized. During 2022–23, Chinese imports undercut domestic prices by 10–20 per cent, and their landed prices remained below the domestic industry's cost of sales, depressing domestic prices and constraining the industry's ability to earn remunerative returns.[61]

By 2023, China accounted for virtually all of India's recorded imports of aluminium frames for solar panels/modules. India subsequently imposed an anti-dumping duty of US $403–577 per tonne on anodized aluminium-frame imports from China in 2024, effective for five years.[62]

H&H Aluminium, Insolation Energy and Vishakha Renewables currently operate dedicated aluminium-frame manufacturing facilities, with additional capacity expected to come online over the next few years. However, domestic production remains dependent on imported manufacturing equipment, particularly extrusion presses and anodising lines sourced from China.

Quantifying import dependence is complicated by the absence of a dedicated HS code for solar aluminium frames. DGTR identifies 76109010, 76109030 and 76169990 as tariff lines under which the product covered by its anti-dumping investigation was imported. Import data under these tariff lines therefore provide an indication of import dependence, but may also include other aluminium products.

3 POLICY LANDSCAPE IN INDIA

India is complementing deployment policy with industrial policy through PLI for manufacturing, ALMM for linking market access to domestic production, and trade measures to support domestic industry.

PLI payments are linked to actual production and have yet to be disbursed.

ALMM is extending localization upstream, but domestic production remains more expensive than imports.

According to data from the Organisation for Economic Co-operation and Development (OECD), average subsidies across the sector amounted to 3.75 per cent of annual firm revenue, driven primarily by China and provided mainly through below-market borrowing rates, income tax concessions and, to a lesser extent, grants.[63]

India's approach to solar energy has evolved from a primarily deployment-driven strategy under the National Solar Mission to a broader industrial policy agenda focused on building domestic manufacturing capabilities. The deployment-oriented approach led to large-scale proliferation of imported solar equipment, especially from China.

The policy approach today reflects a shift to green industrial policy, with renewable energy deployment linked with domestic manufacturing.

Manufacturing incentive

Production-Linked Incentive Scheme (PLI)

India's solar manufacturing base is anchored in the Production-Linked Incentive (PLI) Scheme under the National Programme on High-Efficiency Solar PV Modules. Introduced in 2021 and subsequently expanded, the scheme aims to support domestic manufacturing across different stages of the solar value chain. The incentive is given for five years, tapering towards the end.[64]

The scheme was implemented in two tranches. Tranche I, launched in 2021 with an outlay of Rs 4,500 crore, rewarded firms primarily for the scale of manufacturing capacity they proposed and the extent to which they would integrate the solar PV value chain, from polysilicon to modules. Tranche II subsequently expanded the scheme and divided applicants into three baskets based on their level of integration: polysilicon-to-module, wafer-to-module, and cell-to-module.

The section in brief:

- **No PLI money has been disbursed as of July 2026:** The scheme pays only on actual production, starting one year after a project is commissioned—a window that has not elapsed for any project. The first payouts are likely to start in late 2026.

- **Capacity build-up in pipeline**: By March 2026, projects supported under the scheme had established around 30 GW of module, 10.5 GW of cell and 2 GW of wafer-ingot manufacturing capacity.

- **The scheme strongly rewards vertical integration:** In the first tranche, the extent of integration across polysilicon, ingot/wafer, cell and module production carried the same weight as manufacturing capacity and effectively determined the ranking of the highest-scoring bidders. The second tranche retained integration as a central organising principle.

- **Employment delivery is below projections**: Analysis from audited disclosures point to 0.5–0.6 direct jobs per MW of module capacity, against the three jobs per MW projected when the scheme was approved.

How the scheme pays—and why no money has flowed yet

- The PLI is not an upfront capital subsidy. No money changes hands when a project is approved or built: incentives are paid on actual production, over five years, with payments tapering towards the end, and the scheme pays out only from one year after a project is commissioned. That window has not yet elapsed for any Tranche I project, which is why no PLI money has been disbursed so far. The first payouts are likely only from late 2026.

Targets and progress

Table 9: Progress against the stated objectives of the solar PLI Scheme[65]

The table compares the original objectives of the PLI Scheme with implementation progress based on the latest publicly available data as of July 2026

Objectives	Progress
It is estimated that about 65 GW per annum manufacturing capacity of fully and partially integrated, solar PV modules would be installed.	Under the scheme, 30 GW of solar PV module, 10.5 GW of cell manufacturing and 2 GW of wafer-ingot manufacturing has been set up (as of March 2026)[66]
The scheme will bring direct investment of around Rs 94,000 crore.	Attracted investment of Rs 52,900 crore (September 2025)[67]
Creation of manufacturing capacity for balance of materials like EVA, solar glass, backsheet, etc.	
Direct employment of about 195,000 and indirect employment of around 780,000 persons	44,000 jobs added of which 11,220 are direct jobs (September 2025)
Import substitution of approximately Rs 1.37 lakh crore	Imports of solar PV modules declined from $4,354 million in 2023–24 to $995 million in 2025–26—a decline of $3,359 million. In contrast, cell imports increased from $1,853 million to $3,058 million, while wafer imports fluctuated from $330.75 million to $388.51 million.
Impetus to research and development to achieve higher efficiencies in solar PV modules	Lack of a measurable indicator

Source: Compiled from various sources

HOW WERE THE PLIs AWARDED?

Tranche I of the scheme opened for applications in 2021 against a total outlay of Rs 4,500 crore. Fifteen applicants registered, spanning standalone renewable-energy companies (Vikram Solar, Waaree Energies, Premier Energies), renewable-energy arms of larger conglomerates (Tata Power Solar, Reliance New Energy Solar), and other infrastructure players. Each was scored out of 100, split evenly between two criteria.

- Manufacturing capacity (out of 50): The largest promised capacity, 4,000 MW, was set as the benchmark and scored full marks, eight of the 15 applicants matched it.

- Extent of integration (out of 50): how many upstream stages of the value chain—polysilicon, ingot/wafer, cell, module—a bidder committed to building within a single integrated facility, and how quickly.

With most bidders clustering near the maximum on manufacturing capacity, the extent-of-integration score became the effective tie-breaker for the top ranks. Only four applicants secured the highest integration score of a full polysilicon-to-module commitment within three years, and, since the Rs 4,500 crore outlay could not stretch beyond the top three, these scores determined the final award list.

Table 10: Ranking and allocation of beneficiaries under the first tranche of the solar PLI Scheme (2021)

The first tranche rewarded firms proposing large manufacturing capacities and deep vertical integration across the solar PV value chain

Rank	Company	MW promised	Capacity score (/50)	Integration score (/50)	Total (/100)	PLI amount (Rs crore)
1	Shirdi Sai Electricals Ltd	4,000	50	50	100	1,875
2	Reliance New Energy Solar Ltd	4,000	50	50	100	1,917
3	Adani Infrastructure Pvt. Ltd	4,000	50	50	100	663 (of Rs 3,600 asked)
4	FS India Solar Ventures Pvt. Ltd	3,009	40	50	90	Not funded—outlay exhausted

Source: IREDA

The three funded top-ranked bidders all committed to the hardest tier—full polysilicon integration.

Tranche II: Restructured the competition into three capacity baskets by level of integration, each with its own applicant pool and outlay.

Table 11: Allocation of PLI Tranche-II incentives across manufacturing integration baskets

The second tranche of the PLI Scheme divided applicants into three manufacturing-integration baskets, with separate financial allocations for each. The table compares the budgeted outlay with the value of incentives ultimately awarded

Basket	Scope	Allocated (Rs crore)	Awarded (Rs crore)
1	Polysilicon + Wafer + Cell + Module	12,000	7,575.6
2	Wafer + Cell + Module	4,000	5,310.7
3	Cell + Module	3,000	1,051.3

An important criterion introduced was the module efficiency (share of solar radiation converted into electricity by a module) achieved in the first year of commercial production. If multiple bidders offered the same efficiency, higher second-year efficiency commitments and five-year local value addition served as successive tie-breakers.

Local value addition (LVA) also became considerably more stringent. Falling short of the prescribed LVA by up to 3 percentage points triggers penalties, and a shortfall beyond 3 points forfeits that year's incentive entirely.

Table 12: Trajectories of local value addition

Manufacturers will have to fulfill certain minimum values of module performance (combination of module efficiency and module's temperature coefficient) and Local Value Addition for being eligible for PLI

Basket	Year 1 (%)	Year 2 (%)	Year 3 (%)	Year 4 (%)	Year 5 (%)
Polysilicon + Wafer + Cell + Module	75	78	82	86	90
Wafer + Cell + Module	60	65	70	75	85
Cell + Module	50	55	60	65	75

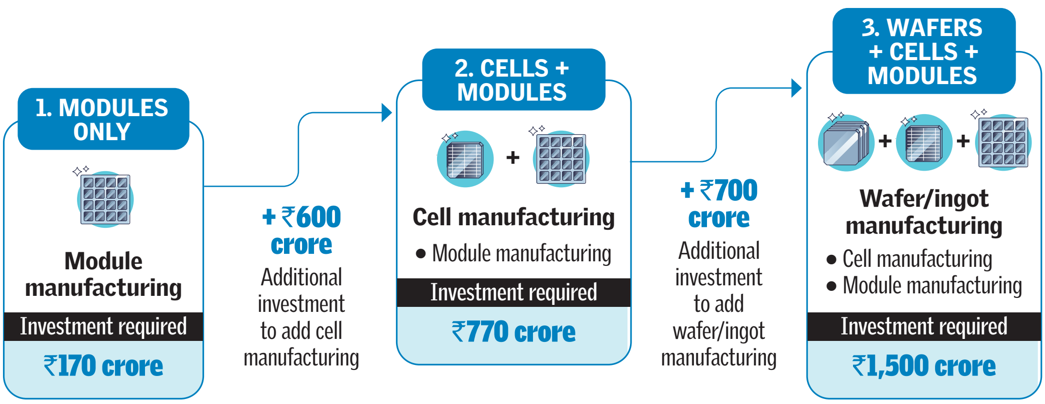
Source: MNRE[68]

In a response in Parliament, the government cited a lack of prior domestic experience in upstream manufacturing, challenges related to importing technology and capital equipment, limited availability of a skilled workforce, and land-related issues as key constraints.[69]

The integration challenge in PLI

One significant challenge in PLI is its focus on fully integrated manufacturing and the very high capital investment required for upstream production.

Figure 10: Capital investment rises steeply as manufacturing moves upstream



Source: IEEFA and JMK, graph: CSE

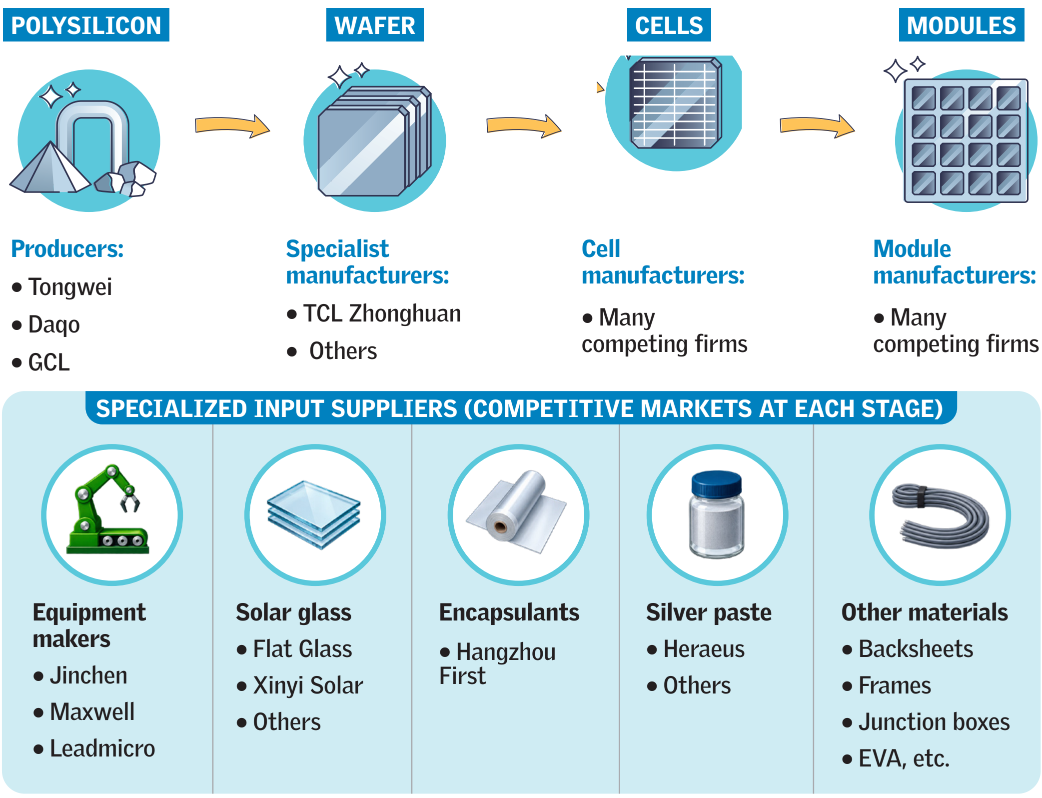
Underlying these capital requirements is a structural difference in how integration is achieved in a country like China and how the PLI requires it to be achieved in India.[70]

China's case of ecosystem integration

Chinese solar manufacturing is integrated at the level of the industrial ecosystem, not the individual firm—each stage of the value chain is served by markets of specialized, competing suppliers.

- Firms specialize in one or two stages and procure the rest from competitive suppliers;
- Inputs available at close to marginal cost through deep supplier ecosystems; and

Figure 11: Integration in China through markets of specialized, competing suppliers



Source: CSE

- Even China's nominally integrated majors procure substantial volumes of intermediates from these markets, which allows any single firm to specialize, buy the rest at close to marginal cost, and limit its capital exposure to one or two stages.

India: firm-level integration

- There is no allied supplier industry ecosystem in India at scale.

- Wafer capacity stands at roughly 2 GW against over 219 GW of module capacity, and inputs from metallization paste to advanced encapsulants remain import-dependent (see *Beyond modules*).

- PLI's firm-level integration scoring means that firms must internalize every stage, on their own balance sheet. In comparison to the Chinese ecosystem, the disadvantages of this could be:

Each integrated project carries the full capital intensity of the value chain and its compounded risk—a delay or failure at any upstream stage strands the investment downstream of it.

The employment questions

Employment has been central to the rationale for promoting domestic solar manufacturing since the PLI scheme's inception. When the Union Cabinet approved the PLI scheme in 2021, it projected around 30,000 direct jobs from 10 GW of integrated capacity, an intensity of three direct jobs for every megawatt, alongside 1.2 lakh indirect jobs. Scaled to the expanded scheme, the target became 1.95 lakh direct jobs against 65 GW. Delivery has been harder to pin down. An IEEFA–JMK assessment counts roughly 38,500 direct jobs against the 31 GW of PLI module capacity commissioned by mid-2025, while data placed before Parliament puts direct employment in PLI-linked module units at around 11,220 as of October 2025.

The divergence reflects differences in how employment is measured.

- Existing estimates do not state whether they adjust for contractual tenure—so a contract worker who spent seven months on site counts the same as a permanent employee who worked all year.

- This study uses employment figures from the draft prospectuses of five of India's ten largest module manufacturers. Then converts the headcount into

HOW MANY JOBS DOES A GIGAWATT CREATE?

The arithmetic applied to the audited employment disclosures of India's largest module makers gives an answer: one megawatt of module manufacturing capacity supports about 0.5–0.6 direct full-time jobs. A gigawatt-scale module plant, in other words, is a workplace of 500–600 people. Cell manufacturing, the stage India is now building at speed, is more automated still, at roughly 0.35–0.4 jobs per MW. These are direct factory jobs only; survey-based estimates suggest roughly three indirect jobs for every ten MW of module capacity.

The number will keep falling as TOPCon lines running imported Chinese equipment replace older ones; each new gigawatt arrives with fewer workers than the last.

full-time employment equivalents. A contract worker employed for seven months out of 12 is counted as roughly 0.6—not one job.

- Two of the five companies chosen run cells and modules at the same site and report one combined workforce. Their headcount is split between the two stages using NREL's published benchmarks for how labour-intensive each stage is relative to the other.

The resulting full-time equivalent jobs we get are **0.5–0.6 direct jobs per megawatt** (see *Annexure IV*).

The government's promised intensity of three direct jobs per MW is five to six times what company disclosures indicate actual module-line employment to be.

The case for making solar equipment in India cannot rest primarily on factory employment. The stronger arguments lie elsewhere, in supply security, in the ancillary industries that grow around manufacturing, and in the engineering capability the sector builds.

Approved List of Models and Manufacturers (ALMM)

The section in brief:

- **ALMM is a market-access instrument**: List-I determines which module manufacturers and models are eligible for government-supported projects, while List-II establishes eligibility requirements for solar cells under the specified domestic-content mandate.

- **Two lists are currently in force**: List-I for modules, first issued in March 2021, and List-II for cells, first issued in July 2025. An ALMM List-III for wafer manufacturers is slated to be introduced in 2028.

- **The mandate is moving upstream**: Utility-scale projects whose bids were submitted after 31 August 2025, as well as net-metering and open-access projects commissioned from 1 January 2027, are required to use modules made with cells from manufacturers enlisted under List-II. Residential rooftop consumers under the PM Surya Ghar 'Give It Up' category remain exempt until March 2027.

- **The cell mandate carries a cost**: Domestic cells currently command a price premium over duty-paid imported cells, creating an additional procurement cost for projects covered by the mandate. This opportunity cost is estimated later in this paper.

What is ALMM?

To improve the quality, reliability and traceability of solar panels, the Ministry of New and Renewable Energy introduced the ALMM through an order issued in 2019.

ALMM is a procurement-linked domestic market-access mechanism that creates assured demand for solar manufacturing in India by limiting suppliers for government-supported projects. It consists of two categories: List-I, which includes approved manufacturers and models of solar PV modules, and List-II, which includes approved manufacturers and models of solar PV cells (see *Annexure I*). While ALMM List-I for modules was first released in March 2021, ALMM List-II for cells was first released in July 2025.[71] An ALMM List-III for wafer manufacturers is slated for release in 2028.

From quality registry to localization mandate

A key feature of the ALMM framework is that only the manufacturers and models included in the ALMM List-I are eligible to supply solar PV modules for government-supported projects. Utility-scale projects whose bids were submitted after 31 August 2025, and net-metering and open access projects commissioned on or after 1 January 2027, must now use modules built with cells from enlisted domestic manufacturers, with residential rooftop consumers under the PM Surya Ghar 'Give It Up' category exempt until March 2027.[72,73]

The framework has therefore evolved from a mechanism focused on quality and traceability into an instrument of localization: enlistment now determines market access, while its extension from modules (List-I) to cells (List-II), and potentially wafers (List-III), takes the mandate progressively further upstream in the value chain.

The opportunity cost of ALMM

With ALMM List-II in force from 1 June 2026, India has extended domestic content compulsion one stage deeper into the solar value chain, from modules to cells. Because domestically produced cells remain costlier than duty-paid imports, this expansion has a measurable procurement cost.

The additional cost depends on just three factors:

- how many solar cells must be sourced domestically because of the mandate;
- how much more a module made with Indian cells costs than one made with imported cells; and
- the alternative being compared against (imported cells from China).

In this analysis, imported cells are assumed to have already paid all applicable duties, including basic customs duty, the agriculture infrastructure and development cess and anti-dumping duties. The estimate therefore captures only the extra cost created by the ALMM cell mandate itself, and not the broader protection already provided through import tariffs.

The capacity build-up, weighting conventions and assumptions are set out in *Annexure II*.

The price gap is assumed to be around US $0.10 (i.e. 10 cents) per watt: a module made with Indian cells costs about that much more than one made with imported cells, according to Premier Energies, an estimate other manufacturers have broadly corroborated. The gap should, however, narrow as the enormous capacity now under construction reaches the market and competition sets in.

Opportunity cost estimate:

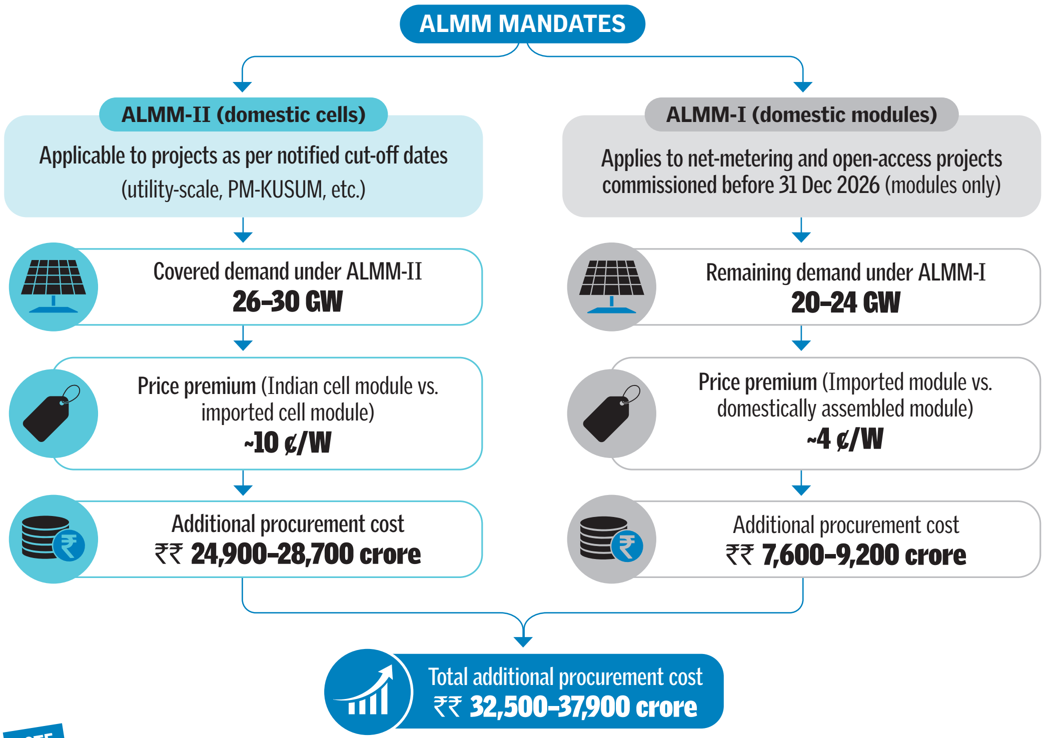
DCR modules (with Indian cells) installed x price premium (over modules with Chinese cells) = Additional procurement cost
26–30 GW x 10 ¢/watt = **Rs 24,900–28,700 crore**

An important caveat

This estimate captures only the incremental cost arising from ALMM List-II. It does not include projects that remain subject only to ALMM List-I.

While ALMM List-II applies to utility-scale projects awarded after the notified cut-off dates, net-metering and open-access projects commissioned before 31

Figure 12: Estimated opportunity cost of ALMM mandate for FY2026–27



NOTE

- ALMM-II estimate applies only to projects covered under its scope. Demand estimated at 26–30 GW.
- Domestic cell production (35–40 GW) is expected to exceed the mandated demand (26–30 GW) in FY2026-27.
- Earlier cut-off (31 May 2026) would have led to higher demand (45–50 GW); the revised cut-off substantially reduces this.

Source: CSE

December 2026 continue to be governed solely by ALMM List-I, which requires the use of domestically manufactured modules but does not mandate domestically manufactured cells.

Based on the methodology described in Annexure II, the demand falling exclusively under ALMM List-I is estimated at 20–24 GW during FY2026–27. The current price premium between an imported module and a domestically assembled module using imported cells is estimated at around US ¢4/W.

Applying this premium results in an additional procurement cost of **Rs 7,600–9,200 crore** attributable to the remaining ALMM List-I mandate.

Overall procurement cost

Combining the estimated costs under both mandates suggests an overall additional procurement cost of approximately **Rs 32,500–37,900 crore** during FY2026–27.

The magnitude of this cost is significant. At current prices, the additional procurement cost in a single year exceeds the 24,000 crore allocated under both phases of the PLI scheme for solar manufacturing.

Who bears the cost?

The additional procurement cost raises the upfront capital cost of solar projects. The eventual impact on electricity tariffs will depend on financing costs, project performance and bidding conditions, but the premium is ultimately recovered over the operating life of the project through slightly higher tariffs.

The estimate should, however, be interpreted with three important caveats.

First, the estimate does not include several indirect costs. If domestic supply proves insufficient, developers could face higher prices due to shortages, project commissioning could be delayed, and the government would collect less customs revenue as imports decline.

Second, the policy's long-term success depends on whether manufacturing costs fall over time. If economies of scale and greater domestic integration reduce the price gap from around 10 cents to 5 cents per watt, the mandate's annual cost would roughly halve even as manufacturing volumes increase.

Conversely, if India extends domestic content requirements to wafers under ALMM List-III before domestic production becomes cost-competitive, the additional cost could rise again.

This opportunity cost may nevertheless be worth bearing. Domestic manufacturing may remain more expensive than sourcing from the lowest-cost global producers in the near term, but some of this cost may be justified if it builds capabilities, diversifies supply and strengthens resilience over the longer term. The policy challenge may therefore not be to eliminate these costs altogether, but to ensure that the additional cost borne today has a defined horizon and yields commensurate gains in long-term resilience and industrial capability.

Trade policy

Duties on imports

India has increasingly relied on tariff-based protection to support domestic solar manufacturing. In April 2022, the government imposed Basic Customs Duties (BCD) of 40 per cent on imported solar modules and 25 per cent on imported solar cells. In addition, a Social Welfare Surcharge (SWS) of 4 per cent on modules and 2 per cent on cells was imposed. The objective of the policy was to reduce import dependence, encourage domestic manufacturing investment, and create market certainty for Indian producers.

In early 2025, the BCD was reduced from 40 per cent to 20 per cent for solar modules and from 25 per cent to 20 per cent for solar cells. However, the tariff structure became more complex with the introduction of an Agriculture Infrastructure and Development Cess (AIDC), set at 20 per cent of the applicable BCD on modules and 7.5 per cent on cells.[74]

An Integrated Goods and Services Tax (IGST) of 5 per cent is also levied on the assessable value of the imported goods, including applicable BCD, AIDC and SWS.

The Indian government also imposed anti-dumping duties ranging from 23–30 per cent on imports of solar cells and modules from China. This may partly explain the growing share of India's solar imports from countries other than China.[75]

Trade disputes

India's solar manufacturing policy has historically attracted scrutiny under international trade rules. The domestic content requirements under the Jawaharlal Nehru National Solar Mission were successfully challenged by the United States at the World Trade Organization. Following this, India shifted towards alternative industrial policy instruments such as production-linked incentives, customs duties and procurement-linked market access measures.

In May 2026, China requested the establishment of a WTO dispute settlement panel to challenge India's tariff regime and elements of the PLI Scheme. China argues that the local value addition requirements embedded within the PLI framework discriminate against imported products and may constitute subsidies contingent upon the use of domestic over imported goods.[76] China has requested the constitution of a dispute panel to review the measures.

The United States, on the other hand, has played an important role in the growth of India's solar manufacturing sector by emerging as the largest export destination for Indian solar modules and cells. However, access to the US market has increasingly been shaped by trade measures aimed at protecting domestic manufacturing. In 2018, the US imposed safeguard tariffs on imported crystalline silicon photovoltaic (CSPV) cells and modules under Section 201 of the Trade Act, initially starting at 30 per cent and declining over time. The measure was extended in 2022 for another four years.[77]

More recently, the US has adopted a more aggressive trade stance towards solar imports. In 2025, Indian exports were affected by broader tariff measures imposed by the Trump administration, while in 2026 the US Department of Commerce imposed preliminary countervailing duties of around 126 per cent and later set preliminary anti-dumping duties of 123 per cent on solar cells and modules imported from India, citing alleged government subsidies and unfair pricing practices.[78] These measures have raised concerns about the long-term viability of India's export-led manufacturing and highlighted the risks of dependence on a single export market.

4 INTERNATIONAL EXPERIENCE WITH SOLAR INDUSTRIAL POLICY

Every major solar market has run some mix of demand-side deployment support and supply-side manufacturing policy, and the outcomes diverge sharply.

Japan and Germany show that creating solar demand does not necessarily create lasting manufacturing competitiveness.

China's advantage goes beyond subsidies, combining scale, specialized suppliers, state-backed finance and coordinated industrial policy.

Japan

Japan accounted for 27.8 per cent of global PV production in 1992, peaking at 50.4 per cent in 2004. This leadership was built on a demand-side strategy—a residential rooftop subsidy programme launched in 1994 that covered nearly half of installation costs.[79] Domestic manufacturers such as Sharp, Kyocera, Sanyo and Panasonic captured the domestic market at a time when imports were not yet cost-competitive. Sharp expanded production roughly 200-fold between 1994 and 2005, by which time it had become the world's largest solar PV manufacturer.

Japan's experience changed after 2012, illustrating the limits of relying on deployment policy alone to sustain manufacturing. The need for alternative sources of electricity following the Fukushima disaster led the government to introduce a generous feed-in tariff.[80] While the policy successfully boosted demand, it contained no domestic-content requirements or manufacturing-linked incentives. As a result, much of the demand it created was met by imported equipment, predominantly from China, where panels had become 20–30 per cent cheaper than their Japanese counterparts.

Japanese manufacturers effectively exited mass PV production by 2019, when Japan's global manufacturing share fell below 1 per cent.

Germany

Germany is widely regarded as the archetype of the feed-in tariff. The Renewable Energy Sources Act (EEG), enacted in 2000, guaranteed technology-specific, cost-based tariffs under 20-year contracts, giving investors predictable returns while periodically reducing tariffs as technology costs declined. As module prices fell rapidly after 2009, tariff reductions were accelerated and linked to deployment volumes to contain government's fiscal costs. The policy was highly successful in driving solar deployment and reducing costs: PV installation costs fell by around 70 per cent between 2000 and 2007.[81]

The programme, however, failed to sustain Germany's manufacturing base. Manufacturers increasingly struggled to compete with rapidly expanding, lower-cost Chinese producers. Between 2011 and 2018, successive insolvencies and acquisitions eliminated leading firms, including Solon, Q-Cells, Conergy and SolarWorld, leaving Germany without a domestic solar cell manufacturer.[82] Although the European Union later introduced anti-dumping measures against Chinese imports, these came too late to reverse the industry's decline. Germany's experience demonstrates that demand-side policy alone cannot sustain manufacturing competitiveness once domestic firms lose their cost advantage.

Industry assessments also suggest that German manufacturers remained concentrated in module production, where competition was driven primarily by price, rather than shifting towards higher-value segments such as high-efficiency cells and advanced technologies.

United States

The United States relied almost entirely on demand-side tax credits for decades before adding a dedicated manufacturing-side lever. The Investment Tax Credit dates to the Energy Tax Act of 1978 at 10 per cent, rose to 30 per cent under the Energy Policy Act of 2005, and has been extended repeatedly, most recently through the Inflation Reduction Act of 2022 at 30 per cent through 2032, with a bonus of 10 percentage points each for domestic content. The Production Tax Credit ran in parallel at a statutory base of 1.5 cents/kWh.[83]

The IRA's addition was Section 45X, the Advanced Manufacturing Production Credit, a per-unit, output-linked subsidy paid on domestic production of modules, cells, wafers, polysilicon and other clean-energy components, giving the United States, for the first time, a manufacturing-side instrument targeted at the same value-chain segments China dominates. The Trump administration's 2025 amendment accelerated phase-out timelines for the rule and tightened supply chain restrictions in a bid to significantly limit the act's utility.

The United States and India run the two most structurally similar policy stacks. An output-linked manufacturing credit, layered on demand-side support (investment-tax credits and solar rooftop subsidy, respectively), defended by trade measures (countervailing duties and safeguard duties, and Basic Customs Duty with cesses, respectively) and reinforced by content rules (the domestic-content bonus and ALMM, respectively).

The principal difference lies in policy certainty. PLI provides a fixed five-year incentive once awarded, whereas the US tax credits are subject to congressional changes. That stability, however, cuts both ways, as the previous chapter notes. The trade-off is that PLI payments cannot easily be adjusted as production costs or technology evolve.

China

The preceding chapters document China's production dominance stage by stage. Some important features of the ecosystem include:[84]

- A two-tier command structure combining central direction with subnational execution, in which provinces and municipalities compete to attract plants with land, power and capital access through state banks at a scale unmatched elsewhere.

- An early and short-lived demand subsidy phase, the Golden Sun programme launched in 2009 and wound down by 2013. The programme was discontinued once installation targets were met ahead of schedule.

- A manufacturing base whose share significantly dominates at every stage of the value chain.

5

SUNNY SIDE UP: WHAT COMES NEXT?

Solar panels made in China are cheaper than those made in India. How can India-made modules become more cost-competitive with Chinese imports without duties?

How far upstream should India go, and where can domestic capacity deliver the greatest strategic value?

Where should the next phase of industrial support be directed: towards manufacturers, or towards the equipment, materials and component ecosystem?

Solar manufacturing today is characterized by rapid technology change, competitive global prices, shifting supply chains and continuously evolving production capacity. Policies appropriate under one set of market conditions can quickly become insufficient, economically distortive or even irrelevant under another.

The expansion of India's solar manufacturing base raises two broader questions for the next phase of industrial policy. First, how can India-made modules become more cost-competitive? Second, how far upstream should India seek to build domestic capacity? The answers are not straightforward: some interventions may strengthen manufacturing in the long term but increase costs in the short term, while others may improve competitiveness without necessarily improving strategic resilience.

How can India-made solar panels become more price competitive?

Solar panels made in China are cheaper than those made in India. This paper traces the sources of that gap : import duties that raise the cost of cells and other inputs for module makers; a component ecosystem that keeps solar glass, encapsulants, backsheets and metallization paste import-dependent; plants operating at a fraction of Chinese scale; and costlier power and capital.

This begs another set of questions:

a. **What should be the role of protection as domestic manufacturing scales up?**

The current policy mix of duties and ALMM mandates has created a protected market for Indian panels. Duties can provide space for domestic manufacturers to scale while raising the cost of imported inputs, particularly cells, for downstream manufacturers. Should protection then be linked to measurable improvements in domestic scale, supplier capacity and cost competitiveness?

b. **What would close the cost gap?**

China's cost advantage is rooted in production scale, deeply integrated and specialized supply chains and access to abundant and patient capital, none of which can be created through a per-watt production incentive alone.

While India now has more than 219 GW of module manufacturing capacity (ALMM notified), under PLI-supported manufacturers only about 30 GW of module capacity is committed, implying that the large majority of investment is occurring outside the scheme, and before any incentive had been disbursed. For large conglomerates, the investment case arguably existed independently of the incentive, and the real value of a PLI award may lie less in the subsidy than in the signalling and market-access advantages it confers. The evolving cell technology further erodes the real value of a fixed five-year outlay. This begs the question whether fiscal resources are better directed at firms that would likely have invested regardless, or at the specialized supplier industries such as equipment, materials, and components, where the private investment has not materialized on its own.

Should the next stage of industrial support, therefore, focus on the underlying determinants of competitiveness, such as supplier ecosystems, technology, scale and access to affordable finance?

The experience of other Indian manufacturing sectors illustrates this progression. India's automobile industry became competitive through technology partnerships, supplier development and sustained domestic demand. The Maruti-Suzuki joint venture catalysed technology transfer, while phased localization and vendor-development programmes created an indigenous component ecosystem that today supports one of the world's largest auto-component industries. Although local-content requirements were later withdrawn following WTO rulings, the industry's competitiveness endured because the underlying manufacturing ecosystem had matured.

c. **How should India build technology capability?**

Cost competitiveness is not only a function of scale and input costs. Technological capability may itself need to be treated as an industrial policy objective. How can industrial policy complement firm-level initiatives such as technology acquisition, licensing and strategic partnerships with institutional mechanisms that support the acquisition, adaptation and diffusion of technology across the wider manufacturing ecosystem?

Taiwan's Industrial Technology Research Institute built Taiwan's semiconductor industry by acquiring foreign technology publicly, operating pilot manufacturing facilities, training engineers and diffusing technological capabilities across domestic firms.

How far upstream should India go?

A 100,000-tonne polysilicon plant requires US $1–1.2 billion in capital, a minimum viable scale of 40,000–50,000 tonnes, and 45–55 kWh of electricity per kilogram produced. Indian production is projected at US $17–18/kg against Chinese spot prices of US $4–6/kg. Most polysilicon projects proposed in India so far have been delayed, scaled back or cancelled.

On the other hand, much of the technological value and intellectual property sits upstream, and supply chains are heavily concentrated there, with wafers being the narrowest chokepoint of the chain, China holding 97 per cent of production capacity.

The question therefore is, does supply-chain resilience require India to produce polysilicon domestically, or could the strategic objective be achieved through diversified sourcing and domestic capacity at selected stages of the chain?

Should the next frontier of policies build the supplier ecosystem?

The Balance of Material (BOM) components, metallization paste, solar glass, encapsulants, backsheets and aluminium frames continue to be imported partially or substantially, and this dependence both feeds the cost gap and leaves module capacity exposed to external supply disruption. The creation of BOM capacity was a stated objective of the PLI scheme, and yet the dependence on imported components remains substantial. These industries share a common profile: they are capital-intensive, technologically specialized, and unviable without assured offtake. Redirecting industrial policy towards supplier ecosystems would improve value addition and generate additionality by supporting investments that are unlikely to occur without public intervention.

India’s solar manufacturing policy has succeeded in creating capacity at unprecedented speed. The next phase presents a different challenge: determining which forms of policy support can translate that capacity into internationally competitive production, and where domestic manufacturing provides sufficient strategic value.

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Annexures

Annexure I

Table 13: Approved List of Models and Manufacturers (ALMM) list-II (Solar PV Cells) (as of July 2026)

Company	Capacity (MW)	Technology	Efficiency (%)	Location
Waree Energies	1,328	PERC	22–23.7	Navsari, Gujarat
Waree Energies	3,923	TOPCon	24–25.8	Navsari, Gujarat
Renewsys	452	TOPCon	24–25.6	M. Ranga Reddy, Telangana
Reliance	1,238	HJT	23.8–25.6	Jamnagar, Gujarat
Jupiter Solartech	991	PERC	20–23.8	Solan, Himachal
Websol Energy	1202	PERC	19–23.6	24 Pargana, West Bengal
Fujiyama Power	1,077	PERC	22.6–23.6	Gautam Buddha Nagar, Uttar Pradesh
Evervolt Solar	1,074	PERC	22–23.5	Tirupati, Andhra Pradesh
Mundra Solar	2,298	TOPCon	24.5–25.7	Mundra, Gujarat
Premier Energies	1,358	TOPCon	24–26	M. Ranga Reddy, Telangana
FS India Solar	3,433	CdTe	18–19.3	Pillaipakkam, Tamil Nadu
TP Solar	4,480	PERC	22–23.7	Tirunelveli, Tamil Nadu
TP Solar	53	TOPCon	22.5–25.5	Tirunelveli, Tamil Nadu
Tata Power	280	PERC	20–23.5	Electronic City, Bengaluru, Karnataka
Emvee Energy	1,553	TOPCon	20–26	Bengaluru, Karnataka
Premier Energies	1,925	PERC	20.97–25.63	M. Ranga Reddy, Telangana
ReNew	1,766	PERC	22.4–23.8	Dholera, Gujarat
Jupiter International	779	PERC	20–23.8	Solan, Himachal
Mundra Solar	1,939	PERC	22.6	Mundra, Gujarat
Avaada Electro	610	TOPCon	24.5–26.3	Nagpur, Maharashtra

Source: Ministry of New and Renewable Energy, Government of India[85]

Annexure II

Estimating the opportunity cost of the ALMM-II cell mandate

Metric and counterfactual

The analysis estimates the additional procurement cost created by ALMM List-II. This is calculated as the volume of cells covered by the mandate multiplied by the price difference between domestically produced and duty-paid imported cells. The estimate is limited to direct procurement costs and does not include broader economic benefits, supply-chain security, or indirect costs such as shortages and project delays.

Estimating the utilization rate of cell manufacturing facilities

India's installed solar cell manufacturing capacity increased from 17.4 GW at the beginning of 2025 to around 26.4 GW by the end of the year, with approximately 9 GW of new capacity added during the year.[86,87,89] Since newly commissioned manufacturing lines do not operate for the entire year, their contribution to annual production is adjusted based on the number of months they are expected to be operational. Throughout this analysis, each new manufacturing line is assumed to begin commercial production two months after its announced commissioning date, allowing time for stabilization. Its contribution to annual capacity is then rated according to the number of months it operates during the year.

Table 14: Cell capacity additions and weighted availability, CY2025

Company	Capacity added (GW)	Effective operation month	Weighted contribution (GW-yr)
Waaree Energies (Phase 1)	1.40	February 2025	1.28
Others	1.00	May 2025	0.5
Emmvee Photovoltaic	0.44	June 2025	0.26
Waaree Energies (Phase 2)	4.00	August 2025	1.67
Premier Energies	1.20	August 2025	0.50
Websol Energy System	0.60	November 2025	0.10
Adani (ANIL)	0.40	December 2025	0.03
Total additions	9.04		4.35

Weighted availability for CY2025: 17.4 GW (opening base) + 4.35 GW-year (additions) = 21.75 GW-year. Effective operation months as compiled from company announcements. Source: Various sources

Estimating utilization

The National Institute of Solar Energy (NISE) records 17.6 GW of DCR-certified cell production in CY2025. Since the portal only records production certified under domestic content requirement (DCR) schemes, it does not capture all cell production. The reported figure therefore represents a minimum estimate of India's total cell output.

Compared with the estimated effective manufacturing capacity of 21.75 GW-years, this implies a utilization rate of at least 80 per cent. To account for the incomplete production data and the fact that many new manufacturing lines will still be ramping up during FY2026–27, this analysis assumes a utilization range of 75–85 per cent.

Estimating available capacity in FY2026–27

The analysis begins with 29.8 GW of manufacturing capacity listed under ALMM List-II as of 30 April 2026.[89] This is broadly consistent with Mercom's estimate of 27 GW of installed capacity at the end of 2025 and industry estimates of around 31 GW by mid-2026.[90]

Although approximately 61 GW of additional capacity has been announced for commissioning during FY2026–27, most of it will become operational only partway through the year. After adjusting each manufacturing line for the number of months it is expected to operate, these additions contribute around 17.2 GW-years of effective capacity (see *Table 17: Announced cell capacity additions with FY2026–27 as commisioning dates*).

This results in an estimated 47 GW-years of effective manufacturing capacity during FY2026–27. Applying the assumed utilization rate of 75–85 per cent gives an estimated domestic cell production of 35–40 GW.

Table 15: Announced cell capacity additions with FY2026–27 commissioning dates

Company	Capacity (GW)	Announced commissioning	Effective month	Weighted (GW-yr)	Source
Goldi Solar	1.20	April 2026	Jun 2026	1.00	Saur Energy
Jupiter International (Baddi Unit IV)	1.25	June 2026 (commissioned)	Aug 2026	0.83	Saur Energy, Jun 2026
Avaada Electro (Phase 1)	3.00	July 2026 (commissioned)	Sep 2026	1.75	PV magazine India, Jul 2026
Premier Energies (Phase 1)	4.80	Mid-2026	Sep 2026	2.80	Saur Energy
GREW Energy	3.00	Mid-2026 (ALMM List-II applied)	Sep 2026	1.75	PV magazine India
Insolation Energy (INA Solar)	4.50	September 2026	Nov 2026	1.88	Saur Energy
Premier Energies (Phase 2)	2.20	September 2026	Nov 2026	0.92	Saur Energy
Saatvik Green Energy	4.80	Q3 FY27 (Nov 2026)	Jan 2027	1.20	PV Tech
Vikram Solar	9.00	December 2026	Feb 2027	1.50	PV magazine India, Jun 2026
ReNew Photovoltaics (Dholera)	4.00	December 2026	Feb 2027	0.67	Company / BII release, May 2025
Adani Solar (Mundra/ANIL)	6.00	End-CY2026	Feb 2027	1.00	PV magazine India (2024 guidance)
Jupiter International (Nagpur)	3.00	End-CY2026	Feb 2027	0.50	Saur Energy
Avaada Electro (Phase 2)	3.00	H2 FY27 (assumed December 2026)	Feb 2027	0.50	PV magazine India

Company	Capacity (GW)	Announced commissioning	Effective month	Weighted (GW-yr)	Source
Rayzon Solar	5.10	Operational Feb 2027 (as announced)	Feb 2027	0.85	Company announcement
Websol Energy System	0.15	February 2027	April 2027	0.00	Saur Energy
Emmvee Photovoltaic	6.00	End-FY27	FY28	0.00	Saur Energy
Total	61.0			17.2	

Note: effective operation from the announced commissioning month plus two months, except Rayzon, whose announcement itself distinguishes commissioning (December 2026) from operational status (February 2027). Capacity announced for FY28 or later (Waaree's Unn plant, Emmvee, Reliance, Solex, Gautam Solar, Jakson, FS Solar, IB Solar, RenewSys) is excluded. Source: Various sources

Estimating the volume covered by the mandate

The volume affected by the mandate is limited by two factors: the amount of domestic cell production available and the demand covered by ALMM. Since estimated domestic production is 35–40 GW and mandated demand is around 26–30 GW, the analysis assumes an affected volume of 26–30 GW. The installations under ALMM List I mandates cover open-access and net-metering projects commissioned before 1 January, estimated at 20–24 GW.

Estimating the price premium

The analysis assumes a price premium of US 10 cents per watt, representing the difference between the cost of a module manufactured with Indian cells and one manufactured with imported cells. This estimate is based on industry data reported by Premier Energies and supported by other manufacturers.

The 10-cent estimate reflects market conditions immediately after the implementation of ALMM List-II, when domestic supply was still limited. As additional manufacturing capacity becomes operational, increased competition is expected to reduce this price difference. To reflect this uncertainty, the analysis can also consider a range of 5–10 US cents per watt.

Annexure III

Announced build-up of solar wafer capacity

Table 16: Planned and under-construction solar manufacturing capacity in India

Company	Location	Capacity (GW)	Status/timeline
Waaree Energies	Butibori, Nagpur, Maharashtra	10	Started construction
Premier Energies	Naidupeta, Andhra Pradesh	10	Target 2028
Adani Solar	Mundra SEZ, Gujarat	8	Target 2027–28
Tata Power Renewable Energy (TPREL)	TATA steel SEZ, Odisha	10	Target January 2028

Company	Location	Capacity (GW)	Status/timeline
ReNew Energy Global	Anakapalli, Andhra Pradesh	6.5	Target April 2028
Vikram Solar	Gangaikondan, Tamil Nadu	12	Target FY2029–30
Avaada Electro	Nagpur, Maharashtra	3	Announced
Grew Energy	Kathua, Jammu and Kashmir	2.8	Started construction May 2024
Grew Energy	Narmadapuram, Madhya Pradesh	8	Target March 2028
Emmvee Photovoltaic Power	Devanahalli, Bengaluru (Karnataka)	9	Target FY29 and FY30
Reliance New Energy	Jamnagar, Gujarat	10	Pilot ready in 2026; rest announced
Indosol Solar	Ramayapatnam, Andhra Pradesh	10	Target 2027
JSW Energy	NA	1	Target 2028
TOTAL		100.3	

Source: Compiled by CSE from various sources

Annexure IV

Measuring the employment intensity of solar manufacturing

Employment intensity is measured in full-time equivalents (FTE) per MW of manufacturing capacity. FTE converts a mixed permanent-and-contractual workforce into one comparable figure using a standard working year of 2,080 hours (a 40-hour week).

Employment data are drawn from the draft red herring prospectuses (DRHPs) of companies among India's ten largest module manufacturers that have filed to list in the past one to two years.

Two of the five operate combined module and cell lines, so their workforce must be apportioned between the two stages before a module coefficient can be computed.

The apportionment uses relative labour intensity per MW of cells versus modules, anchored in the NREL benchmarks.

Table 17: NREL benchmark labour intensities (FTE per MW)

Stage	PERC	TOPCon
Module manufacturing	0.70	0.50
Cell manufacturing	0.45	0.15

Table 18: Measured direct employment intensity, module manufacturing (FTE per MW), weighted average of sampled companies

Cell-to-module labour-intensity ratio	7.5-month contractual tenure	9-month contractual tenure
75 per cent	0.50	0.56
60 per cent	0.52	0.58

India is building a solar manufacturing industry at remarkable speed. Most of this capacity, however, remains concentrated in modules, with only a fraction extending upstream.

This report maps the evolving landscape across the solar PV value chain. It examines where manufacturing capacity is emerging, where import dependence persists, what is driving the competitiveness gap with China, and how domestic policies and trade measures have shaped—and are being shaped by—the industry they set out to build. It also considers the trade and competitiveness pressures facing Indian manufacturers in an increasingly competitive global market.

The study brings together the economics of manufacturing, technology dependence, trade flows and the evolution of India's industrial-policy response. It asks where India should build capacity, how far upstream it should go, and where to direct the next phase of support.

Centre for Science and Environment
41, Tughlakabad Institutional Area, New Delhi 110 062
Phone: 91-11-40616000 Fax: 91-11-29955879
E-mail: cse@cseindia.org
Website: www.cseindia.org