C. Policy measures taken internationally can guide India's strategy

Table ES 1 summarises the various kinds of support provided to the solar manufacturing industry in China, India, South Korea, Southeast Asia (Malaysia, Thailand, and Vietnam), Taiwan, and the United States. China stands out for supporting its manufacturers by leveraging all the means listed; its comprehensive strategy is the key reason for its global solar supply chain dominance today. Our analysis of measures taken by various nations highlights the importance of providing access to capital and focusing not just on research and development but also on deploying new technologies.

Table ES 1 China stands out by providing the highest number of benefits and support measures to domestic solar manufacturers

S.No.	Support provided	China	India	South Korea	Southeast Asia	Taiwan	United States
1	Manufacturing subsidies and incentives	✓	✓		✓		
2	Dedicated access to debt capital	✓					
3	Other financial support from the government (equity, grants, loan guarantees)	✓				✓	✓
4	Manufacturing hubs and regional government support	✓			✓		
5	Technology transfer and R&D thrust	✓		✓			✓
6	Targeted demand creation and incentive structure for high-efficiency products	✓	✓	✓		✓	
7	Tariffs and other import barriers to support domestic products	✓	✓	✓		✓	✓

Source: CEEW-CEF analysis

D. Recommendations

India must implement a multi-year solar manufacturing technology roadmap, initiate measures to unlock export markets, and provide measures to support manufacturers set up and scale up upcoming factories

The MNRE has introduced critical near-term support measures such as the basic customs duty (BCD) and PLI scheme. A long-term strategic approach is now essential to bring sustainability to the sector and establish Indian manufacturers as technology leaders. India needs to establish a framework to ensure that new technologies are deployed in the market. To do so, it needs to bring together academia, industry, and international experts. Critically, industry must play a more significant role if laboratory concepts are to be successfully commercialised. India must also open up new sources of demand through innovative routes to help manufacturers compete globally.

Our recommendations, listed in Table ES 2 and detailed in Chapter 6, focus on three strategies to support solar manufacturing:

i. setting up a long-term solar manufacturing technology roadmap, backed by five elements (detailed below),

ii. strategically opening up avenues for export demand, and

iii. providing measures to help manufacturers set up and scale up upcoming manufacturing facilities.

India's solar targets and climate ambitions promise a deep, long-term market for Indian manufacturers. The PLI, BCD, and ALMM have set the stage for rapid manufacturing capacity expansion over the next three years. Policymakers must now take strategic measures to position the Indian solar manufacturing industry as a domestic force and a global leader in terms of technology and market presence.

Image: Goldi Solar

Table ES 2 A focus on technology, demand, and scale is essential to support the domestic solar manufacturing industry

S.No.	Recommendation	Timeline	Implementing authority	Nature of expense
	Set up a long-term solar manufacturing technology roadmap with enhanced funding, a dedicated R&D division in MNRE, and an advisory board.			
1	Identify thrust areas and timelines based on key research requirements and establish solar research funding grants.	2022–2028	MNRE	Grants
2	Incentivise industry-led R&D by (i) setting up a central R&D centre, (ii) providing capex subsidy for manufacturers setting up R&D facilities, and (iii) mandating a minimum spend of 3 per cent of revenue on R&D from 2025.			Capex outflow, subsidy
3	Target partnerships with reputed international solar research institutes and leverage these connections to apply for international research funding programmes.			Nil
4	Set up an independently managed investment fund with anchor investment from the Government of India.			Equity
5	Mandate that solar projects awarded under government tenders use products developed under the solar technology roadmap for a minimum of 5 per cent of their capacity.			Nil
	Strategically create export demand for Indian modules			
6	Create markets for low-carbon manufacturing by (i) providing approval and support for open-access renewable power consumption, (ii) trade deals with nations that have stated a preference for low-carbon products.	2022–2023	MNRE, Ministry of External Affairs (MEA), state regulators	Nil
7	Enhance financing for solar projects in developing countries that are members of the International Solar Alliance (ISA) through India Exim Bank, securing export demand for Indian modules.	Rolling	MNRE, MEA, India Exim Bank	Loan
8	Consider expanding the ALMM list and bilateral duty exemptions based on trade deal negotiation requirements.	Rolling	MNRE	Nil
	Support scale for upcoming manufacturing capacity			
9	Raise the share of loans to the RE manufacturing sector to 20% of Indian Renewable Energy Development Agency's (IREDA) loan book by 2026.	2022–2026	IREDA	Loan
10	Set up manufacturing hubs with attractive land rates, labour availability, deemed open-access approval, and thrust sector status for solar manufacturing.	2022–2023	State industrial development corporations	Revenue outflow
11	Apply BCD on polysilicon or wafer imports from 2027, start tapering BCD on cells and modules from 2025.	2025 onwards	MNRE	Nil

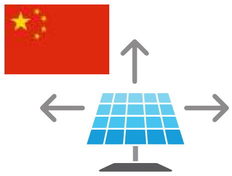
Source: CEEW-CEF analysis

With manufacturers around the world announcing large capacity expansions, Indian companies face a competitive global market.

Image: Goldi Solar

1. Introduction

The process of manufacturing solar modules consists of four stages – (i) making polysilicon, a highly pure form of elemental silicon, (ii) converting polysilicon into silicon wafers, (iii) processing wafers into solar cells, and (iv) assembling solar cells into modules. Chinese solar manufacturers dominate each of these steps, holding a 67 per cent market share in polysilicon, 97 per cent in wafers, 79 per cent in cells, and 71 per cent in modules, as of 2019 (Garg et al. 2021). They were able to achieve this market concentration due to the strategic importance given to solar manufacturing by the Chinese central and provincial governments since the 2000s. State support enabled solar manufacturers to stay afloat during crises and construct large-scale, integrated gigafactories over 2015 to 2020. Chinese companies now dominate the solar manufacturing value chain, research and development, and equipment and ancillary materials manufacturing. Localising the supply chain has helped Chinese solar manufacturers cut costs and achieve scale. Leading Chinese players are doubling down on their market dominance and have announced large-scale manufacturing capacity expansions across the supply chain. Estimates suggest that Chinese manufacturers announced capacity expansion plans totalling 340 GW of wafer, 170 GW of cell, and 160 GW of module manufacturing in 2021 (Ranjan 2022b).



Leading Chinese manufacturers are doubling down on their dominance and have announced large-scale capacity expansions across the solar value chain

India's cell, wafer, and polysilicon manufacturing lags not just China's but also that of other Asian countries such as Malaysia and South Korea (PVPS 2021). Currently, India has 11 GW of module, a 2.5 GW of cell, and no polysilicon or wafer manufacturing capacity (MNRE 2021a; Joshi 2021). Further, India is heavily dependent on imports for bill of material (BOM) components in solar manufacturing. In contrast, by the end of 2021, the global manufacturing capacity of polysilicon is expected to reach 230–250 GW, wafer 310 GW, cell 325 GW, and module 400 GW (Duggal 2021a; Clean Energy Associates 2021; PV Magazine 2021).

While India's solar manufacturing sector has failed to significantly grow so far, domestic manufacturers have an opportunity to aggressively expand their presence and benefit from a favourable policy landscape. The years, 2020 and 2021, saw large-scale supply chain disruptions and global shortages in polysilicon and other raw materials, which have led to a 40 per cent increase in the price of imported solar modules.[6] These disruptions highlight the criticality of a robust and fully integrated domestic manufacturing industry. Simultaneously, global overcapacities of wafer, cell, and module production promise a competitive global market. This report outlines a broad set of recommendations for Indian policymakers to establish a robust and technology-led solar manufacturing sector.

6. Between October 2020 and October 2021, as per CEEW-CEF analysis of Cybex import data for HS Code 854140.

Methodology and objectives

Today, photovoltaic (PV) solar is predominantly based on two technologies – crystalline silicon and thin film. Crystalline silicon accounts for 95 per cent of global production (Fraunhofer ISE 2021). Therefore, this report only discusses crystalline silicon solar cell manufacturing, given its market dominance. Our recommendations focus on long-term strategic measures in addition to short-term actions. To build our recommendations, we collected inputs from Indian solar experts (list of experts provided in Acknowledgments) and analysed the literature on global solar technology and market trends.

We provide a brief overview of recent policy measures to support the industry and detail the key technologies currently operational in solar manufacturing. We also expand on projections regarding the global solar technology landscape and identify key considerations for Indian solar manufacturers as they set up new facilities and scale up. Acknowledging the benefits of learning from other nations, we discuss how China, South Korea, Taiwan, Malaysia, Thailand, Vietnam, and the United States have supported their solar sectors.

2. Will manufacturing policies finally deliver?

Image: iStock

India's first policy attempts to support domestic solar manufacturing included a 2012 scheme to provide capital expenditure subsidies and a 2011 policy establishing domestic content requirement (DCR) for projects set up in India. However, these measures failed to significantly develop solar manufacturing. Manufacturers faced delays in subsidy distribution, while the DCR policy allowed exemptions for thin film modules and was ultimately discontinued as it was not compliant with World Trade Organisation rules. Further, India's solar capacity development occurred through the reverse auction route, which encouraged aggressive tariff decline, instead of the feed-in tariff route. Developers preferred low-cost imports over relatively expensive domestic products (Jain, Dutt, and Chawla 2020). MNRE imposed a safeguard duty on imported products in 2018, however, the duty was applicable for only two years and did little to support domestic manufacturers.

Since March 2021, MNRE has taken steps to resolve uncertainties in the solar manufacturing sector regarding and bring in fiscal support and strong protections for domestic manufacturers. Three initiatives are discussed briefly below:

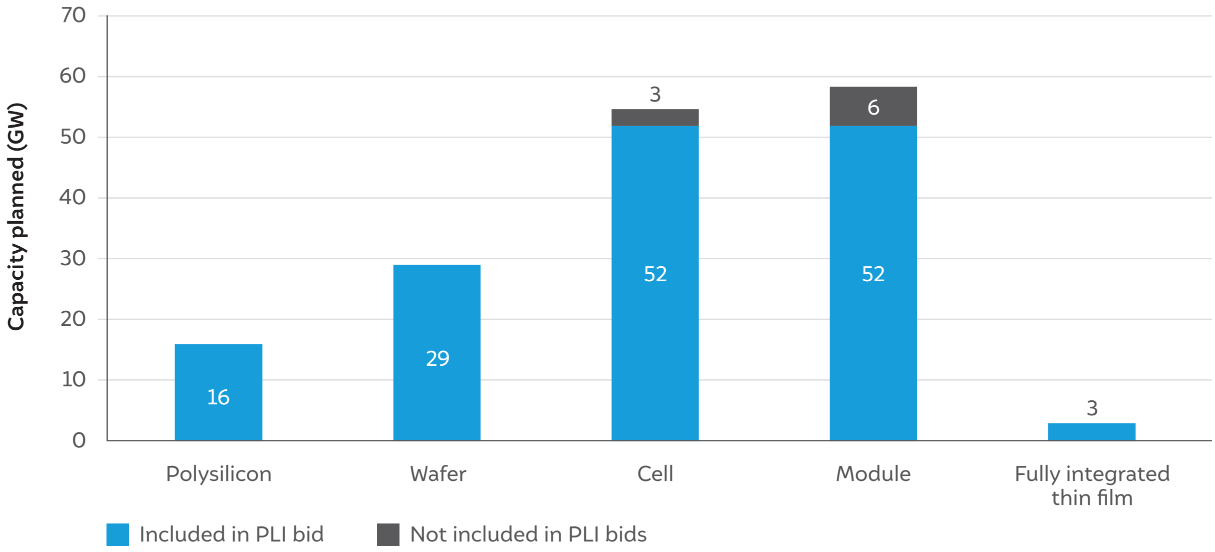
Bids for the PLI scheme totalled to 55 GW, marking a significant shift in India's solar manufacturing plans

- **Basic customs duty**: In March 2021, the MNRE introduced a BCD of 40 per cent on solar module imports and 25 per cent on solar cell imports, effective from 1 April 2022 (MNRE 2021b). While the BCD will make domestic manufacturing cost-competitive, it is likely to lead to a 20–25 per cent increase in solar tariffs (CEEW-CEF 2021).
- **Production-linked incentives**: In June 2021, the MNRE initiated the auction process for the *Production-linked Incentive* (PLI) scheme with a layout of USD 600 million (INR 4,500 crore) over five years.[7] The PLI scheme provides revenue incentives of INR 2.25–3.75 per Wp for solar modules up to 50 per cent of the capacity set up under the scheme (MNRE 2021c). The incentive rate depends on the module's efficiency and degradation. The scheme saw an overwhelming response with 55 GW worth of bids, of which 16 GW was for polysilicon to module manufacturing, 13 GW for wafer to module manufacturing, 23 GW for cell to module manufacturing, and 3 GW for thin film manufacturing (Koundal 2021). In November 2021, the government awarded incentives to three manufacturers, totalling 12 GW of fully integrated solar manufacturing, from polysilicon to modules, under the PLI scheme (IREDA 2021a). In 2022, the government sanctioned an additional USD 2.6 billion (INR 19,500 crore) to expand the list of PLI awardees (Ministry of Finance 2022a). The existing award and additional sanction will ensure the rapid scaling-up of Indian solar manufacturing across all process stages.
- **Approved List of Models and Manufacturers (ALMM)**: In March 2021, the MNRE released List-I under the ALMM. Only solar modules included in List-I are eligible for use in government projects, government-assisted projects, projects under government schemes and programmes, open-access, and net-metering projects installed in the country. This includes projects that supply electricity to government bodies. The MNRE plans to follow this up with List-II, which will consist of approved solar cell manufacturers. List-I manufacturers will then have to mandatorily source cells from List-II to be included in the ALMM. Currently, List-I only includes domestic manufacturers, effectively acting as a non-tariff barrier against imported modules. The latest version (December 2021) of this list includes 41 players with a total capacity of 10.9 GW, of which factories over 500 MW in size make up 64 per cent (MNRE 2021a).

Indian solar manufacturers have announced a spate of capacity expansions in response to these policy measures. While most manufacturers announced expansion plans under the PLI scheme, others have announced new capacity plans outside the scheme as well. Figure 1 represents the sum of these announcements and submissions to the PLI scheme.

7. USD-INR conversion at USD 1 = INR 75, based on average USD-INR exchange rate in 2021 (data from Financial Benchmarks India Limited).

Figure 1 **Recent announcements and PLI submissions total 161 GW of new manufacturing capacity split across different stages**



Source: CEEW-CEF compilation

Image: Om Shanti Retreat, Gurgaon

While passivated emitter and rear contact (PERC) dominates global solar manufacturing today, a transition to n-type technologies is underway.

Image: iStock

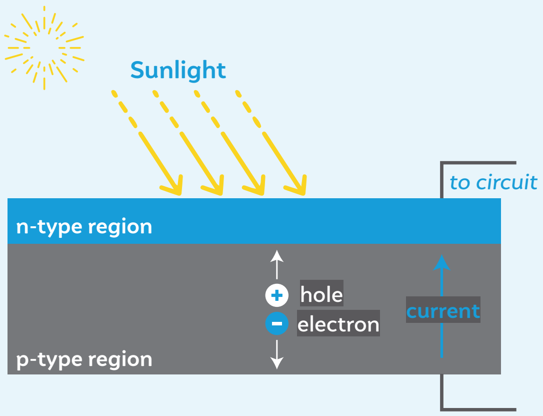
3. The solar technology landscape

With the Indian solar industry and policy pillars finally seeing some much-needed alignment, it is important to go a step further and assess the solar technology landscape. Over time, solar manufacturers have introduced drastic changes in manufacturing processes. These improvements have led to a rapid increase in solar efficiency, bringing down the levelised cost of electricity. In this section, we discuss the basics of solar power generation (Box 1) and how manufacturers have optimised cell manufacturing to improve the efficiency of their products. We also detail the current and future technology landscapes.

BOX 1 How do solar cells generate power?

A solar cell is essentially made of silicon, a semiconductor. It generates electricity from sunlight through the photovoltaic (PV) effect. When sunlight falls on silicon, the photons present in sunlight energise the silicon atoms. When an atom is energised, a valence electron is knocked out of its bond with the silicon atom, creating a free electron and a hole. Electrons from adjacent covalent bonds move into the hole, in turn creating a new hole, effectively resulting in the movement of holes. The movement of these electrons and holes facilitates the flow of electricity, generating power. The PV effect may be intensified by adding small impurities that greatly increase concentration of electrons or holes. These impurities are called dopants. If the dopant contains fewer valence electrons than silicon (less than four), it is called a p-type dopant (e.g., boron and gallium, which contain three valence electrons). If it contains more valence electrons than silicon, it is called an n-type dopant (e.g., phosphorous, which contains five valence electrons). P-type (positive) dopants increase hole concentration, while n-type (negative) dopants increase electron concentration. In the p-type region of the cell shown in Figure 2, holes will be the majority carriers of current, while electrons will be the minority carriers. The opposite will occur in the n-type region.

Figure 2 A solar cell generates power through the photovoltaic effect



Source: CEEW-CEF compilation

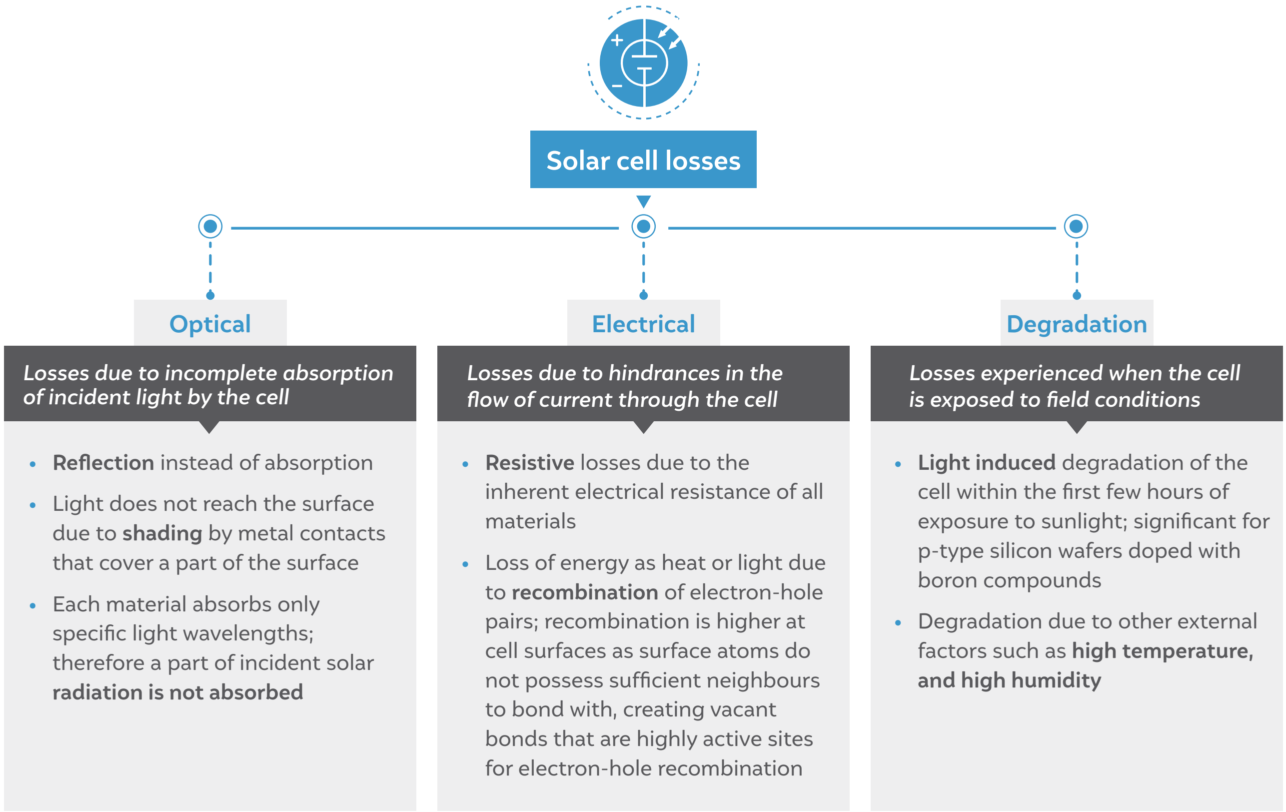
Additionally, electrical systems require current to flow in a single direction in a circuit. As shown in Figure 2, This is facilitated by creating a p-n junction in solar cells. The bulk body of the solar cell is doped with one of the two dopant types, while a small layer at the front is doped with the opposite charge. This ensures that electrons flow in a single direction through the solar cell. A single solar cell typically consists of a single p-n junction that generates a very low voltage (typically 600–700 mV). Typically, 60–72 solar cells are connected in series to generate enough voltage for practical applications. A solar cell's performance is typically measured by its efficiency, which is defined as the share of incident solar power that can be converted to usable power. It is an important measure of performance as a more efficient module can provide higher power output than a less efficient module of the same size. Efficiency improvements are a major driver in reducing solar costs.

When solar cells are assembled into modules, additional efficiency losses are incurred due to optical and electrical losses resulting from the addition of encapsulating layers and other parts of the solar module. Mismatches in cell alignment can increase losses. Solar cells based on the dominant solar technology in the market are up to 23.6 per cent efficient, while modules with these cells are typically up to 21.5 per cent efficient.

3.1 Understanding solar manufacturing

Before discussing the key differentiators across solar technologies, it is important to understand the efficiency losses that these differentiators solve. Figure 3 details the major losses that impact solar cell efficiency.

Figure 3 Power generation from solar cells is subject to three high-level losses – optical, electrical, and degradation



Source: CEEW-CEF adaptation from UNSW (2017) and Axelevitch and Golan (2010)

Over time, the solar manufacturing process has evolved to improve performance by reducing these losses. Figure 4 depicts the solar manufacturing process for the dominant solar technology (cells with monocrystalline p-type wafers and a passivated emitter and rear contact). The processes shown in Figure 4 are for the technology that dominates the market today. Technological alternatives do exist; e.g., aluminium oxide can be deposited by atomic layer deposition instead of by plasma-enhanced chemical vapour deposition; polysilicon can be made by the fluidised bed reactor method instead of the Siemens chemical vapour deposition process. Further, the process and inputs will differ for different cell and module technologies. For example, glass–glass modules use solar glass on the rear instead of a backsheet.