ISMA
INDIAN SOLAR MANUFACTURERS ASSOCIATION

P3C

Perovskite Solar

India's Atmanirbharta Opportunity in Next Generation PV

A perspective developed in association with the Indian Solar Manufacturers Association (ISMA)



About P3C

P3C Technology and Solutions is building India's first indigenous perovskite solar manufacturing platform. Operating a 100 kW pilot in Gurugram, P3C aims for a 1 GW line by 2030 using domestic materials. This enables India to lead in intellectual property while shaping future policies.

About ISMA

Indian Solar Manufacturers Association (ISMA) is the apex industry body representing leading backward-integrated solar PV manufacturers in India, with strong representation from solar cell and upstream capacity manufacturing.

ISMA engages actively with policymakers, regulators, and industry stakeholders to enable policy frameworks that support domestic value addition, technology advancement, and long-term competitiveness of India's solar manufacturing ecosystem. ISMA's membership reflects significant cumulative capital investments in manufacturing capacity and supply chains, underscoring the industry's commitment to building a resilient and globally competitive solar manufacturing base in India.

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Executive Summary



- India's solar manufacturing scale up over the last five years has built capacity (modules, cells, and growing wafer and ingot lines under the PLI scheme) but not ownership of the underlying technology. Polysilicon, wafers, and most process equipment remain overwhelmingly imported.
- Perovskite is the first solar technology where India can plausibly own the IP rather than license or import it, because the global science base is still being written rather than settled.
- The near term case rests on three pillars: (i) Atmanirbharta through import substitution across materials, equipment, and process licences; (ii) a real, physics based energy yield advantage (lower temperature losses and better low light response) that improves Capacity Utilisation Factor (CUF) and Levelised Cost of Electricity (LCOE); and (iii) local value addition from domestic manufacturing.
- The recommended sequencing is single junction perovskite first, a simpler manufacturing problem with data already being generated by Indian pilot lines, followed by silicon perovskite tandem as the natural next step, building on India's existing and growing TOPCon cell base under PLI.
- This requires a coordinated policy response: continued R&D support for domestic efforts such as P3C Technology and Solutions, a provisional ALMM pathway for next generation technologies with defined stability milestones, and rigorous, transparent techno economic modelling that can withstand the scrutiny applied to any large public investment decision.

1. India's Manufacturing Scale Up: Capacity Without Ownership

India's solar manufacturing story of the last five years has been one of scale without ownership. Module capacity has grown many times over under the Production Linked Incentive (PLI) scheme, exports have multiplied, and India now assembles gigawatts of panels a year. India's rapid growth in solar manufacturing marks significant progress, while key inputs such as polysilicon, wafers, and advanced manufacturing equipment continue to be sourced from global markets. This creates an opportunity to further strengthen domestic capabilities and enhance India's position in the global solar value chain. India has built capacity; it has not yet built the underlying technology, and that gap is the central constraint on genuine Atmanirbharta in solar.

Perovskite and perovskite silicon tandem cells are the first realistic opening to change that pattern, not because the chemistry favours India uniquely, but because the technology itself is still young enough, globally, that no country's IP position is locked in yet. And unlike the IP argument alone, the case for perovskite strengthens further once energy yield and levelised cost are brought into the picture. Single junction perovskite's efficiency and generation characteristics under Indian operating conditions give it a plausible economic, and not just strategic, rationale, with tandem architectures representing the logical next horizon once that foundation is in place.



2. Why Perovskite Technology Is Important for India



Perovskite solar technology offers India a transformative advantage over conventional crystalline silicon by addressing both cost and strategic vulnerabilities in the current solar ecosystem. Unlike silicon, which relies on capital intensive and import dependent supply chains, especially for polysilicon and wafers, perovskites can be manufactured using low temperature, solution based processes that significantly reduce capital expenditure and energy consumption. This enables faster scaling of domestic manufacturing capacity and higher local value addition.

2.1 Perovskite for India

a. Aligns with "Atmanirbhar Bharat" (Self Reliant India)

Perovskites allow domestic production of next generation solar modules, reducing:

- Dependency on imported silicon wafers and cells
- Reliance on Chinese solar supply chains

b. Suitable for India's Harsh Climate and Urban Landscape

Perovskite's device characteristics support India's Panchamrit vision for the sector:

- Silicon modules lose efficiency at high temperatures, with up to 20 to 30 percent output loss in peak Indian summers.
- Perovskite shows a markedly lower temperature coefficient (negative 0.1%/°C, against roughly negative 0.3%/°C for TOPCon silicon).
- This translates into higher realised energy efficiency across Indian climatic conditions, where module temperatures routinely run well above standard test conditions.

c. Transforming India into a Global Solar Manufacturing Hub

- Supports emissions reduction and India's Net Zero commitments through low temperature manufacturing processes.

- Factory capex is lower by roughly 70 to 80 percent compared to conventional crystalline silicon lines.
- Lower dependence on imported equipment and materials across the value chain.

2.2 Import Substitution Impact of Perovskite Technology

India's solar deployment is projected at approximately 50 GW per annum, currently dominated by crystalline silicon technology. However, the upstream value chain, particularly polysilicon and wafers, remains highly import dependent, exposing the sector to supply chain risk and price volatility. Perovskite technology offers a structural shift by eliminating key upstream steps entirely, enabling significant import substitution.

The conventional crystalline silicon value chain runs Polysilicon to Ingot to Wafer to Cell to Module; perovskite bypasses the first three stages altogether.

Table 2.1: Import substitution across the solar PV value chain

Value Chain Stage	Key Material Input	Import Dependence (%)	Annual Import Cost (₹ Cr)	Perovskite Requirement	Perovskite Import Dependence (%)	Perovskite Import Cost (₹ Cr)	Substitution Impact
Polysilicon	Solar grade silicon	100	10,000 to 15,000	Not required	0	0	Fully eliminated
Ingot	Silicon ingot growth	100	Included in wafer cost	Not required	0	0	Fully eliminated
Wafer	Silicon wafers	90 to 100	40,000 to 60,000	Not required	0	0	Fully eliminated
Cell Processing	Chemicals and dopants	40 to 50	4,000 to 7,500	Coating materials	20 to 30	1,500 to 2,500	Reduced dependency
Module Materials	Glass, EVA, back sheets	Low	2,200 to 3,500	Glass and encapsulation	10 to 20	2,500 to 3,500	Broadly comparable
Manufacturing Capex	Equipment and tools	70 to 80	1,50,000 to 1,80,000	Coating and deposition tools	40 to 60	25,000 to 30,000	70 to 80 percent reduction

By removing the polysilicon, ingot, and wafer stages entirely, perovskite eliminates the segments of the value chain where India's import dependence is highest and most structurally entrenched, precisely the segments that TERI, IEEFA, and industry bodies have flagged as the sector's weakest links under the PLI scheme today.

2.3 High Energy Yield and Impact on the Levelised Cost of Electricity (LCOE)

With perovskite technology delivering approximately 25 percent higher energy yield than conventional crystalline silicon, the Capacity Utilisation Factor (CUF) increases from roughly 20 percent to roughly 25 percent, significantly improving generation per MW of installed capacity. The higher output directly enhances the denominator in the LCOE equation, reducing the cost per unit of electricity. When combined with a 30 to 40 percent reduction in capex, driven by the elimination of the polysilicon and wafer stages, the overall LCOE decreases from approximately ₹2.4 to 2.7/kWh for crystalline silicon to ₹1.5 to 1.9/kWh for perovskite, a reduction of roughly 30 to 40 percent. This improvement is structurally driven by both enhanced energy generation and lower capital intensity enabled by import substitution, positioning perovskite as a highly cost competitive pathway for large scale solar deployment in India.

Table 2.2: Crystalline silicon and perovskite compared on LCOE drivers

Parameter	Crystalline Silicon	Perovskite	Impact on LCOE
Capex	₹38 to 42/W	₹22 to 28/W	Decreased 30 to 40 percent
Import Dependence	High (wafer and polysilicon)	Minimal	Decreased cost volatility
CUF / Energy Yield	roughly 20 percent	roughly 25 percent	Increased generation
Annual Generation	roughly 1.75 MU per MW	roughly 2.19 MU per MW	Higher output
Degradation	roughly 0.5 percent	0.5 to 1 percent	Comparable
LCOE	₹2.4 to 2.7/kWh	₹1.5 to 1.9/kWh	Decreased roughly 30 to 40 percent

Two things are worth flagging for anyone reviewing these figures before publication. First, the degradation range shown for perovskite (0.5 to 1 percent) reflects current pilot stage understanding rather than a 25 year bankable track record, since India's field data on long term perovskite degradation is still being generated through programmes such as NISE's reliability testing. This is the one parameter in the table where genuine uncertainty remains widest, and the LCOE range should be read as conditional on that data holding up over time. Second, the temperature coefficient figures in Section 2.1(b) are given here as %/°C to align with how CUF and generation figures are normally modelled; if the underlying modelling instead used a voltage temperature coefficient (mV/°C or V/°C), that is a different physical quantity and worth reconciling before the numbers go external, since technical reviewers are likely to check the units.

2.4 Local Value Addition (LVA)

The combined effect of these technology and manufacturing benefits is projected to generate local value addition of approximately ₹4,000 crore over the next 15 years. A year-wise build-up of this estimate will be published as the underlying modelling is finalised.



3. Scope in India

India's perovskite effort is still at pilot scale, but it is real and moving faster than most people outside the sector realise. The National Institute of Solar Energy (NISE), an MNRE autonomous body, is actively testing indigenously developed perovskite modules, and IIT incubated startups have moved from single digit square centimetre lab cells to reliability testing on modules destined for institutional and real world trials. This is early stage, but it is India origin work (design, absorber formulation, and assembly line all developed domestically) rather than imported technology being localised.

The realistic near term opportunities fall into a few buckets:

- **Utility scale generation on an energy yield argument:** The case for perovskite in India rests on delivering more kWh per installed kW under Indian operating conditions, not on a higher headline efficiency number or a different form factor. This is the same positioning First Solar has used successfully against crystalline silicon globally: a technology that may not lead on rated efficiency can still win on real world energy yield, lower temperature losses, and a stronger cost per kWh outcome.
- **Tandem integration with India's existing silicon base:** Since a silicon perovskite tandem cell uses a conventional silicon bottom cell as its foundation, India's growing TOPCon and cell capacity under PLI is not stranded; it becomes the substrate onto which a perovskite top cell can eventually be added, discussed further in Section 6.
- **Equipment and materials tooling:** Because perovskite deposition equipment is far less capital intensive than polysilicon reactors or ingot furnaces, India has a genuine chance to design and build its own tools rather than import them, closing the equipment gap that plagues silicon manufacturing today.



4. What Makes the Technology Attractive



Beyond the cost, import substitution, and yield case set out above, perovskite's appeal rests on a few additional properties that silicon cannot match, even as silicon itself keeps improving:

- **Tunable bandgap:** The absorber's bandgap can be adjusted by changing its chemical composition, which is what allows it to be layered on top of a silicon cell as a tandem and capture a wider slice of the solar spectrum than silicon alone.
- **Rapid efficiency gains:** Certified silicon perovskite tandem cells have already crossed 35 percent efficiency in the lab as of mid 2026, comfortably above the roughly 29 to 33 percent practical ceiling of single junction silicon, and commercial tandem modules from early movers such as Oxford PV have begun shipping to utility customers.
- **Superior real world energy yield:** As set out in Section 2.3, the combination of a lower temperature coefficient and stronger low light response means perovskite can out generate a silicon plant of identical nameplate capacity over a year, the same "wins on energy yield, not just rated efficiency" argument that has underpinned thin film's commercial success elsewhere.

The caveats are equally real and worth stating plainly to policymakers: moisture and thermal stability, encapsulation durability over a 25 year design life, and the presence of lead in most high performing formulations remain open engineering and regulatory questions globally, not just in India. Any India specific narrative has to be built on realistic timelines for solving these, not around them.

5. Perovskite Against the Other Emerging Silicon Architectures

It is worth placing perovskite alongside the two other advanced silicon technologies India is simultaneously trying to absorb (heterojunction and interdigitated back contact) because they are not really competitors so much as different bets on the same underlying constraint.

Table 5.1: Perovskite against the other emerging silicon architectures

Technology	Typical efficiency today	Manufacturing cost	India's current position	Strategic character for India
TOPCon	roughly 24 to 26 percent	Lowest; compatible with existing PERC lines	PLI scale domestic capacity building up	Scale and cost leadership on an imported architecture
Heterojunction	roughly 24 to 26 percent	Higher; fewer processing steps but pricier materials and equipment	Limited domestic capacity; largely import dependent	Import dependent premium tier
Interdigitated Back Contact	Up to roughly 24.5 percent	Highest; complex rear contact patterning and alignment	Effectively no domestic capacity	Import dependent premium tier
Perovskite Tandem	35 percent plus certified at cell level	Top cell is relatively low capex; overall economics still maturing	Pilot scale, India origin R&D already underway	The one architecture where India can be a first mover on IP

Heterojunction and interdigitated back contact are both routes to squeezing more efficiency out of silicon, and both are technologies where India is, once again, a taker rather than a maker, as the equipment and process know how to originate elsewhere. Perovskite tandem is different only in one respect, but it is the respect that matters most for this conversation: India's own institutions and startups are already generating IP in it, at a stage early enough for that IP to matter globally.



6. Sequencing the Roadmap: Single Junction First, Tandem Next

For policymakers and manufacturers alike, the practical question is not "single junction or tandem" but which to prioritise first, and how the two connect. The recommended sequencing is single junction perovskite as the immediate priority, with silicon perovskite tandem as the deliberate next step once the domestic single junction platform is established.

Why single junction first. A single junction cell removes the need to match a perovskite top cell to a textured silicon bottom cell, a genuinely hard interface engineering challenge that is still limiting tandem module yields globally. For an industry with limited process depth, starting with a single junction lets Indian manufacturers build absorber, encapsulation, and reliability know-how without simultaneously having to master silicon perovskite interface integration. It is also where India's own pilot lines already have live data and real trial customers today, rather than being a technology confined to overseas laboratories, precisely the evidence a forward looking ALMM pathway would need to build stability milestones and enlistment criteria around.

Why tandem is the necessary next step, not an alternative path. Once single junction manufacturing, encapsulation, and reliability capability is established domestically, tandem integration is where the technology's full efficiency ceiling, and India's full strategic opportunity, is realised. Three reasons this matters for the policy conversation specifically:

- **It builds directly on India's existing PLI investment.** A silicon perovskite tandem cell uses a conventional high efficiency silicon cell (TOPCon class) as its foundation. India's growing domestic TOPCon and cell manufacturing capacity under PLI is not stranded by a shift toward perovskite; it becomes the substrate for the next generation, protecting the value of capital already committed under the PLI scheme.
- **It offers the highest efficiency ceiling of any commercially emerging PV architecture.** Certified tandem cells have already crossed 35 percent efficiency globally, well above the practical ceiling for single junction silicon or single junction perovskite alone, a meaningful consideration for land constrained utility sites and for maximising output per rupee of grid infrastructure.
- **It extends India's IP ownership across two technology generations rather than one.** A domestic industry that has already built single junction absorber and encapsulation know how is far better positioned to develop tandem specific IP (interface passivation between the perovskite and silicon layers, in particular) than one that skips straight to tandem without that foundation, or one that licenses tandem technology from abroad.

For manufacturers, this sequencing should inform capital allocation: near term investment in single junction lines and reliability infrastructure, with tandem integration planned as a second phase once domestic single junction yields and degradation data are established. For the Ministry and MNRE, it argues for a two stage ALMM and R&D support pathway, addressed in Section 7, rather than a single, undifferentiated "next generation technology" category.

7. The ALMM Question: Not Exclusion, But a Defined Pathway



Under today's ALMM parameters, largely built around durability track records and bankability metrics established by mature crystalline silicon, a nascent technology like perovskite would struggle to qualify, simply because it has not yet accumulated the multi year field performance data that silicon has. That is a reasonable starting position for a policy built to protect the reliability of government backed and subsidy linked projects. But it should not be read as a permanent ceiling on next generation technologies.

The constructive path is a provisional ALMM category for next generation cell technologies, structured around defined stability milestones (damp heat and thermal cycling benchmarks equivalent to IEC 61215 class testing), a requirement for field pilot data over a specified period, and a time bound route to full List I or List II enlistment once those milestones are met. Consistent with the sequencing set out in Section 6, this pathway should be structured in two tiers: one for single junction perovskite, where India's own field data is already accumulating, and a second, later tier for tandem architectures, once single junction milestones are met and tandem specific reliability data becomes available. This mirrors, in spirit, how MNRE has already begun extending ALMM's scope from modules to cells and is contemplating wafers, an evolving framework rather than a fixed one. A provisional category gives perovskite manufacturers a visible, credible destination without asking the policy to lower its bar for silicon grade projects today.

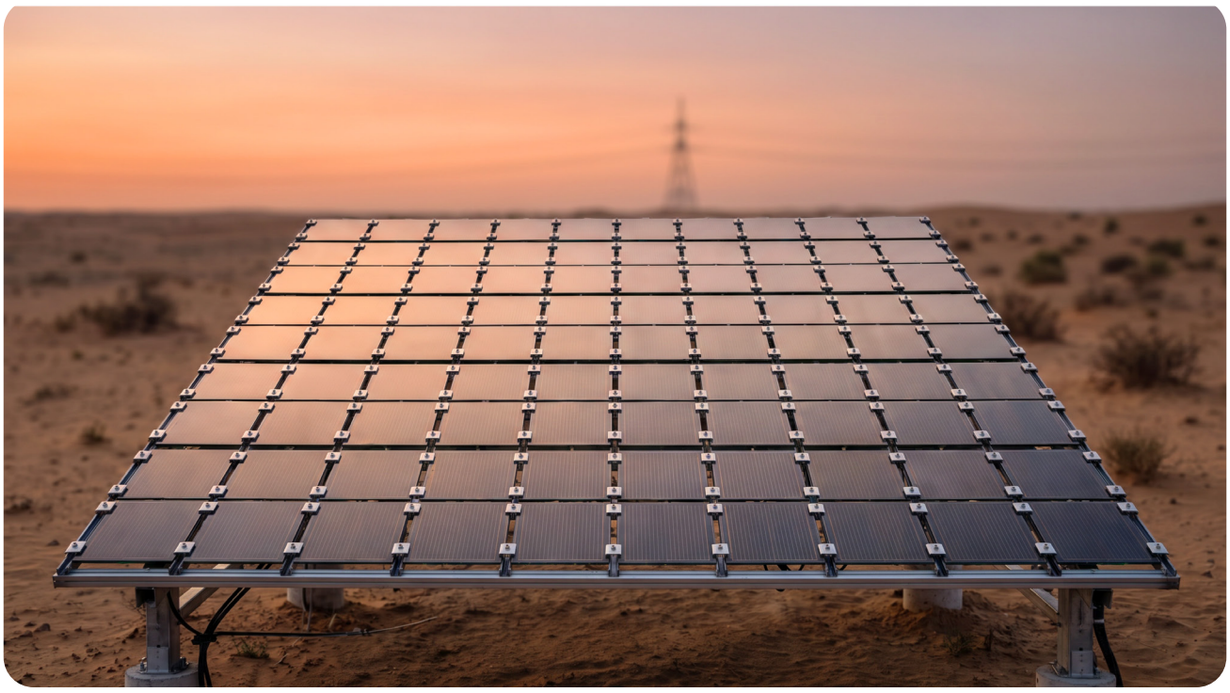
8. The Role of P3C

P3C Technology and Solutions, an IIT BHU spinoff with IIT Delhi incubation support, is currently India's most advanced domestic effort in perovskite commercialisation, and its trajectory illustrates both the opportunity and the distance still to travel. The company has taken perovskite modules from lab scale devices to 30 square centimetre modules at roughly 15 percent efficiency, undergoing reliability testing at NISE, with plans to seek further validation from international labs such as NREL. It has signed an MoU with NISE to build shared testing infrastructure and standardisation benchmarks for perovskite modules in India, and it has recently launched a validation platform aimed at giving other Indian PV manufacturers and technology developers a shared facility to test and generate real world performance data, precisely the kind of field evidence a provisional ALMM pathway, and the CUF and degradation assumptions in Section 2.3, would need.

P3C's significance for this conversation is less about its current efficiency numbers, which are still well below lab records set by global players, and more about what it represents structurally: a domestically owned company developing its own absorber chemistry, its own assembly line, and its own IP, rather than licensing someone else's process. Its priority from here should be building out the reliability and outdoor energy yield data (through NISE and, eventually, international validation) that would substantiate the CUF and temperature coefficient claims in Section 2.3 on a bankable basis, before turning to tandem specific R&D as outlined in Section 6. For ISMA and its member manufacturers, engaging with P3C and similar domestic efforts is a direct way to anchor the sector's IP and import substitution ambitions in something that already exists on Indian soil, rather than treating next generation technology purely as a future policy aspiration.



9. The Way Ahead for the Sector



India approaches the next generation of solar technology from a position of genuine strength. The cell, ingot and wafer capacity now being built under the PLI scheme and ALMM List II gives the country a manufacturing base on which perovskite can be layered, since every commercial silicon perovskite tandem rests on a high efficiency silicon bottom cell of the kind Indian fabs already make. The sensible course is to build in sequence, with single junction perovskite first, where Indian pilot lines already hold live data and trial customers, and tandem integration on domestic TOPCon cells to follow once absorber, encapsulation and reliability know-how is proven at home. Government can enable this through a provisional, two tier ALMM category with clear stability milestones and a time bound route to full enlistment, through dedicated R&D and pilot scale funding under MNRE and the Anusandhan National Research Foundation that sits alongside, and does not draw from, support for upstream silicon, and through independent, published techno economic modelling of the CUF, LCOE and local value addition figures set out in this paper. Manufacturers, for their part, can co-locate pilot lines within operating cell fabs, partner with NISE and domestic developers such as P3C to build a bankable record of field performance, and give degradation data the same weight as efficiency and cost. Pursued together and in that order, these steps give India a credible opportunity to own the technology and the intellectual property of the next generation of solar, with Indian manufacturers leading its commercialisation.




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