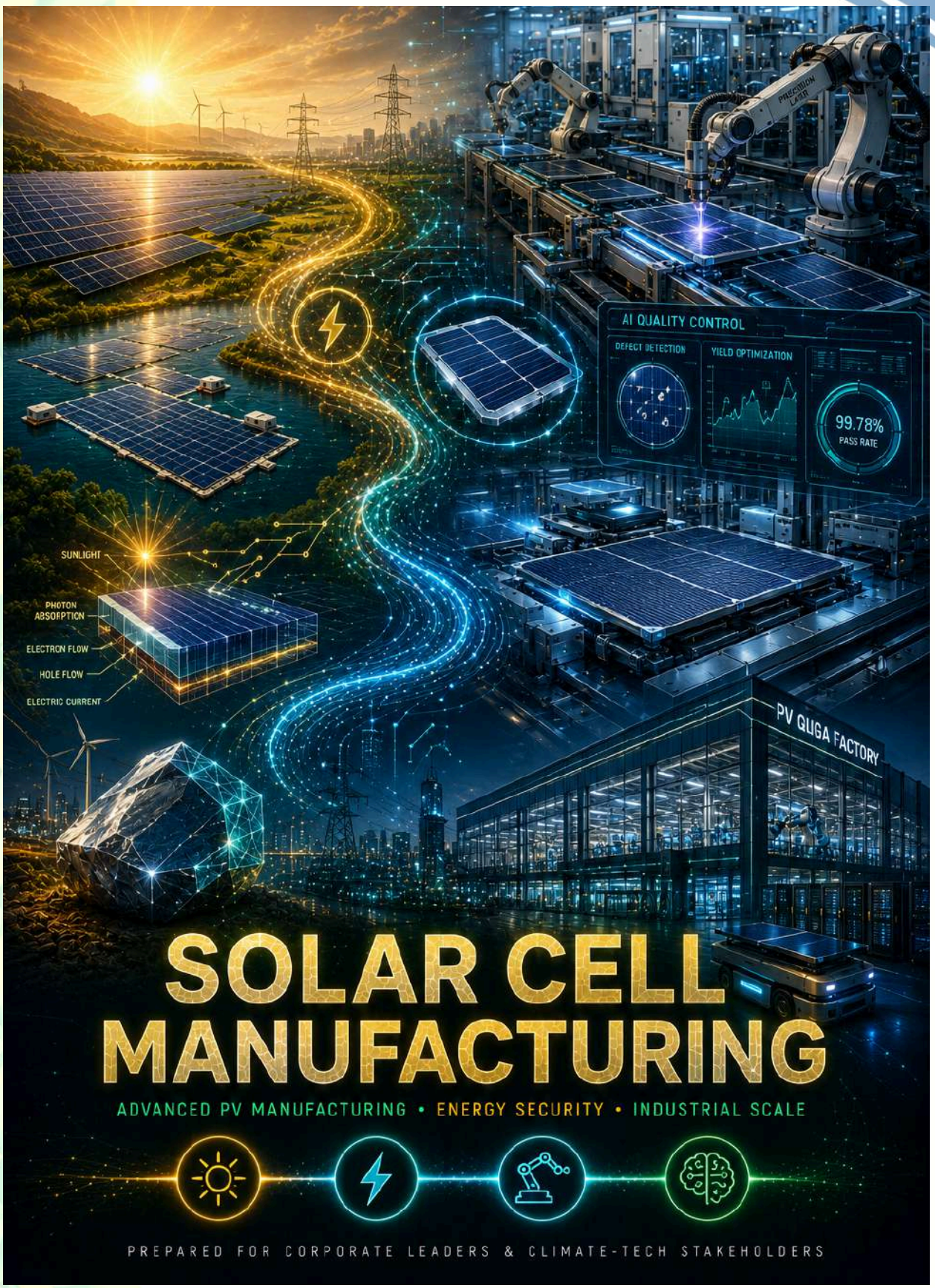
AI QUALITY CONTROL
DEFECT DETECTION
YIELD OPTIMIZATION
99.78%
PASS RATE
SUNLIGHT
PHOTON ABSORPTION
ELECTRON FLOW
HOLE FLOW
ELECTRIC CURRENT
PV GIGA FACTORY
SOLAR CELL MANUFACTURING
ADVANCED PV MANUFACTURING • ENERGY SECURITY • INDUSTRIAL SCALE
PREPARED FOR CORPORATE LEADERS & CLIMATE-TECH STAKEHOLDERS

Solar & Wind

Solar Cell Manufacturing

This section provides key inputs on the Indian Solar Cell Manufacturing Opportunities for corporate leaders

Opportunity Snapshot: Solar Cell Manufacturing

Converts sunlight into electricity by producing photovoltaic (PV) cells.

Market Signal

- Massive module demand ,as India targeting **500GW non-fossil capacity by 2030**
- Strong policy push favours domestic manufacturing **(PLI Schemes + ALMM,BCD)**
- **Annual Market size by 2030:** 20,000 - 25,000 ₹ Cr

What Makes or Breaks It?

- **Technology choice** and timing (TOPCon/HJT vs legacy PERC)
- **Scale** (≥2–5 GW plants) to achieve cost competitiveness
- **Backward integration** of wafer to cell improving margins & control

Why It Matters NOW?

- **Transition to high efficiency tech** (TOPCon/HJT) creating new capex cycle
- Domestic demand + export potential as **global supply chains diversify**
- **Cell manufacturing capacity gap,** import dependence(70-80%) for modules

Well Aligned Opportunity for

- Large industrial groups
- Existing **module manufacturers** moving upstream
- **Electronics/ semicon adjacent players** with precision manufacturing capabilities

Key Challenges

- **High capex ($150-250M/GW)**; as it is tech dependent
- **Upstream dependency** on wafers/polysilicon imports

Business Model

- Greenfield giga-scale plants with PLI support
- JV/tech partnerships with global cell technology providers
- Gradual integration: module → cell → wafer (phased approach)

Introduction and Business Case

India's solar power sector has seen increasing activity on the manufacturing side, transforming from a massive focus on just power generation.

Over the past few years, the government has also taken decisive policy and financial steps to strengthen domestic manufacturing. Initiatives such as the Production-Linked Incentive (PLI) Scheme, Basic Customs Duty (BCD) on imported cells and modules and the creation of Integrated Manufacturing Clusters have catalyzed large-scale investments in solar manufacturing. India's cell manufacturing capacity is rapidly expanding, moving from a few gigawatts of fragmented players to large, vertically integrated facilities capable of producing high-efficiency technologies such as PERC, TOPCon, HJT and bifacial cells.

All the above augur well for India's solar cell manufacturing sector to be humming with activity for the next many years, possibly decades.

Market Potential for Solar Cell Manufacturing in India

Year	Market Size (₹ Cr)	Capacity Outlook	Drivers
2025	10,000-15,000	20 - 30 GW	PLI-backed expansion; ALMM enforcement & Basic Customs Duty
2030	20,000-25,000	50 - 60 GW	Domestic demand + exports; integrated fabs scaling.
2040	30,000-40,000	75 - 80 GW	Net Zero demand; India as a global export hub.

Market Segments and Applications

Segment	Applications	Business Model	Key Drivers
Domestic module manufacturers	Cells used in local module assembly	Long-term supply contracts, spot procurement	ALMM compliance; import substitution; policy protection
Export-oriented module makers	Cells for modules exported to US, EU	Contract manufacturing, export supply agreements	Trade barriers on modules; demand for non-Chinese supply chains

High-efficiency module segment (TOPCon/HJT)	Premium modules for utility, C&I, RTC	Technology-linked supply agreements	Efficiency race; demand for higher yield per watt
Utility-scale projects (indirect demand)	Bulk module production requiring cells	EPC-driven procurement via module makers	Largest volume driver; cost competitiveness critical
C&I and rooftop segment	Smaller-scale, high-efficiency modules	Distributed supply via module OEMs	Preference for high-efficiency, space-constrained installs
RTC / storage-linked projects	High-performance modules for firm power	Premium contracts via module suppliers	Reliability & performance requirements; low degradation cells
Data centers & hyperscalers	High-efficiency, reliable modules	Direct sourcing via module suppliers	Premium demand; ESG and 24×7 clean power needs
Government & PSU tenders	Modules supplied under public programs	Tender-based procurement (via modules)	Stable demand; localization mandates
EPC / developer backward integration	Captive cell consumption	In-house manufacturing (IPP/EPC players)	Margin control; supply chain security
OEM / contract manufacturing (tolling)	Third-party cell production for brands	Tolling / contract manufacturing	Asset-light expansion; brand-driven demand

Typical Project Capacities & Investments Required in India

Project Type	Typical Capacity	Indicative CapEx (₹ Cr)	Notes
Mono PERC	1 - 2 GW	350 - 650	Mono PERC panels are durable, with some models designed to last 35-40 years
TOPCon	1 - 2 GW	400 - 850	TOPCon production lines can be upgraded from existing PERC manufacturing lines with relatively low capital investment, facilitating faster industry adoption.
HJT	1 - 2 GW	650 - 1350	Offers >25% efficiency, superior performance in high temperatures (low temperature coefficient), and high

			bifaciality (up to 93%) to capture sunlight on both sides.

Underlying Technologies and Processes

Element	Options	Key Traits
Cell technologies	Mono-PERC, TOPCon, HJT, thin film (CdTe)	Higher efficiency drives competitiveness; HJT/TOPCon scaling.
Manufacturing processes	Ingot → wafer → cell → module	Vertical integration improves margins and reliability.
Automation & digitalisation	Robotics, AI-driven Quality Control, inline testing	Boosts yield, reduces defects.

Key Challenges

Challenge Area	Key Issues	Business Impact	India Specific	Strategic Implications
Upstream Supply Chain Dependence	Reliance on imported polysilicon, wafers, and equipment; raw material price volatility; logistics risks	Margin fluctuations; procurement uncertainty; exposure to global disruptions	India lacks fully integrated upstream ecosystem; strong dependence on imports	Develop upstream partnerships, pursue backward integration, diversify sourcing beyond single regions
Pricing Pressure & Global Competition	Chinese low-cost manufacturing; rapid global price declines; commoditization	Profitability pressure; risk of inventory losses; tight margins	Domestic manufacturers face cost disadvantages despite policy support	Focus on efficiency-driven technologies (TOPCon, HJT), automation, and export competitiveness
Policy & Regulatory Dependence	ALMM inclusion, import duties, PLI incentives, domestic content requirements	Investment uncertainty; demand timing linked to policy changes	Domestic industry heavily influenced by government policy and trade measures	Policy-aligned manufacturing strategy; flexible capacity planning
Demand Visibility &	Project delays, tender cycles, module	Uneven order pipeline; capacity	Domestic installations fluctuate; module	Secure long-term supply agreements;

Off-taker Dynamics	manufacturer integration; export market barriers	utilization risk	players integrating backward into cells	diversify customer base and export markets
High Capex & Technology Transition Risk	Rapid evolution of cell technologies; large-scale automation needs; high energy consumption	Long payback periods; technology obsolescence risk; financing challenges	Need for giga-scale plants to compete globally; infrastructure and energy cost considerations	Phased investment strategy, JV/technology partnerships, focus on high-efficiency niche segments

Prominent Players in the Indian Market

Company / Entity	Focus Areas
Adani Solar	Having large domestic manufacturing capacity for solar PV cells
Tata Power Solar	Established Indian manufacturer with integrated cell production
AMPIN Energy Transition	Planning cell manufacturing footprint in West Bengal.
Websol Energy System	Kolkata-based manufacturer of high-efficiency solar cells
ReNew Energy	Key manufacturer of solar cells based in Gujarat.
Jupiter International Ltd	Has existing solar cell manufacturing (e.g., mono PERC capacity) and is planning a large cell facility in Butibori, Maharashtra
Premier Energies	Integrated manufacturer operating a 3.4 GW solar cell capacity and 7GW expansion underway in Andhra Pradesh (one of the first Indian players to produce TOPCon solar cells).

Innovation Perspectives

Innovation	Business Opportunity	For Senior Management
From commodity cells to application-specific cells	Segment-tailored cells (utility, rooftop, Round-the-Clock)	Enables pricing power
TOPCon at scale with cost discipline	Ultra-low-cost TOPCon platforms	Protects margins in volume markets
Premium back-contact & high-efficiency niches	IBC / ABC cells for premium rooftops	High ASP, brand pull
Low-carbon & ESG-certified cells	Low-CO_2 cell manufacturing	Access to ESG-premium markets

Trade-resilient manufacturing ecosystems	Multi-region cell fabs	Market access protection
Vertical integration as a volatility hedge	Wafer-to-cell-to-module integration	Margin stability
Storage & firm-power optimized cells	Cells optimized for storage-linked output	Premium project demand
Digital cell manufacturing (Industry 4.0)	AI-driven yield optimization	Improves ROCE
Repowering & replacement cell platforms	Retrofit-specific high-efficiency cells	New brownfield demand
Next-gen cell roadmap ownership	Early bets on HJT & tandem cells	Long-term leadership

Concentric & Satellite Opportunities

- Next-Gen Cell Technology OEM Skids: Concentric equipment providers specializing in turnkey deposition and doping skids for advanced architectures like PERC, TOPCon and HJT/IBC (Heterojunction/Interdigitated Back Contact), driving 25 % cell efficiency.
- Closed-Loop Silicon Kerf and Etch Chemical Recovery: Co-located systems for purifying and recycling high-value raw materials like silicon kerf slurry and expensive etching/cleaning chemicals, drastically reducing raw material input cost and waste.
- Automated Wafer Handling and Defect Sorting: High-throughput, robotic material handling systems integrated with NIR/AI vision to grade and sort silicon wafers (ingots/cells) in real-time, minimizing breakage and optimizing downstream processing.
- Ultra-Thin Wafer Processing Equipment: OEMs focused on precision equipment (slicing, wet processing) capable of handling future ultra-thin (e.g., 100 µm) silicon wafers to cut down on silicon consumption.
- Silver Paste & Metallization: High-conductivity pastes and screen-printing systems for cell front/back contacts.
- AI-Powered Factory Digital Twins: Software platforms creating a virtual replica of the giga-factory to optimize tool sequencing, predict maintenance needs and adjust deposition parameters for consistent cell uniformity and yield maximization.
- Advanced PV Recycling & Critical Material Recovery: Satellite hydrometallurgical or thermo-mechanical recycling facilities focused on high-purity recovery of silver, silicon, copper and glass from End-of-Life (EoL) panels for re-introduction into the supply chain.
- Non-Silicon Cell Material Supply Chain: Upstream ventures developing and scaling stable, high-purity supply chains for alternative cell materials (e.g., Perovskites, Cadmium Telluride (CdTe)) and specialized components like conductive pastes and encapsulants.

- Integrated Building- & Vehicle-Applied PV (BAPV/VAPV) Lines: Satellite manufacturing lines customizing solar modules into high-aesthetic, structural products (e.g., solar tiles, colored glass façades, car body panels) for high-value niche markets.
- PV Module Design for Disassembly (DfD): R&D and engineering firms specializing in new module designs (e.g., utilizing thermal release adhesives, clip-based frames) that enable easy and high-purity separation of components at EoL.
- EoL Panel Reverse Logistics & Repowering Networks: Specialized service providers managing the compliant collection, inspection, refurbishment and efficient transport of EoL panels for either second-life deployment or dedicated recycling centers.

Key Takeaway for Senior Management

Takeaway	Details
Technology choice determines long-term competitiveness, not installed capacity	• The transition from PERC → TOPCon/HJT/back-contact is redefining efficiency benchmarks and bankability • ***Example**:* TOPCon lines delivering >25% efficiency • **Competitive advantage lever:** early adoption of next-gen architectures avoids stranded assets and enables premium module positioning
Upstream control is a financial hedge, not just a supply decision	• Cell margins are highly sensitive to wafer, polysilicon, and paste pricing • ***Sub-components**:* Wafer supply agreements, polysilicon partnerships, silver/copper paste innovation • **Competitive advantage lever:** Partial backward integration or strategic supply lock-ins stabilize margins and attract Tier-1 buyers
Manufacturing yield and process intelligence create hidden margin pools	• Small improvements in yield, scrap rate, and throughput materially affect IRR • ***Examples**:* AI-driven inline inspection, predictive maintenance, process analytics • **Competitive advantage lever:** digital manufacturing platforms outperform pure scale-based competitors
Speed of technology migration is a strategic	• Cell technology cycles are shortening; the ability to upgrade lines quickly becomes a moat

capability	• ***Examples**:* modular equipment design, rapid line retrofits, R&D partnerships

Next Steps for Corporate Leaders

While solar cells present a large growth opportunity for specific corporates and industry segments, there are also significant uncertainties. In addition, success could depend on the right choice of cell technology and partnerships.

This could be an attractive climate tech opportunity for industries and firms in specific sectors and industries keen on catering to this fast growing market.

Connect with Team EAI to know more about this opportunity and take your corporate's initial steps. Send a note to consult@eai.in or talk to Muthukrishnan - 9952910083