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Confederation of Indian Industry

Skill Gap Study for
Solar Sector
in India

Implemented by:

giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH





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Published by
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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46, Paschmi Marg, Vasant Vihar
New Delhi - 110057.



Mr Sujoy Ghosh, Chairman, Renewable Energy Council,
CII-Sohrabji Godrej Green Business Centre and
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India stands at a critical juncture in its clean energy transition. As the country moves decisively towards its commitment to reach 500 GW of non-fossil fuel based power generation capacity by 2030, solar has emerged as the prime mover of this transition. The solar value chain is expanding far and wide across the country with record deployment across utility and decentralised segments; an exponential increase in domestic module and cell manufacturing capacities; and an aggressive push towards backward integration through polysilicon, ingots, and wafers. Solar has truly become the foundation for achieving self-reliance in energy in the country.

Now, it is particularly important to translate multi-gigawatt targets and capital investments into bankable and high-performing assets, and this requires an agile and highly qualified technical workforce. In this context, this report on ***Skill Gap Analysis for the Indian Solar Energy Sector*** provides timely, practical, and ground level insights for workforce development catering to the solar sector.

This study highlights the human resource requirements across the entire solar value chain from upstream polysilicon refining, ingot pulling, and high-efficiency cell fabrication to downstream EPC execution and long-term asset management. The study report delineates the critical competency bottlenecks emerging on modern shop floors and project sites, particularly related to manufacturing, process control, material handling and management, inspection and quality control, and SCADA (Supervisory Control and Data Acquisition) integration. It is paramount to address these gaps to improve product quality, minimise equipment downtime, increase electricity generation, and ensure overall safety without compromising long-term asset reliability. In this context, this study is a proactive step in the right direction in building a resilient talent pipeline for achieving and sustaining global leadership in solar manufacturing and system deployment.

I am glad to note that the quantitative analysis has been significantly enriched through extensive consultations with relevant stakeholders, ensuring that the recommendations directly reflect shop floor and on-field requirements. I am confident that this report will serve as a strategic compass for industry executives, policymakers, and educational institutions working collectively to build a resilient, technically proficient, and skilled workforce that underpins India's competitiveness in solar energy.

I congratulate GIZ, Skill Council for Green Jobs, and the Confederation of Indian Industry for delivering this comprehensive and rigorous assessment. I am sure this initiative will significantly contribute to building an ecosystem of skilled solar workforce in the country.

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List of Abbreviations

AI	Artificial Intelligence
ALMM	Approved List of Models and Manufacturers
BE	Bachelor of Engineering
BESS	Battery Energy Storage System
BOS	Balance of System
CAPA	Corrective and Preventive Action
COP	Conference of the Parties
CUF	Capacity Utilization Factor
DC	Direct Current
DISCOM	Distribution Company
DSCR	Debt Service Coverage Ratio
EL	Electroluminescence
EPC	Engineering, Procurement, and Construction.
EPF	Employees' Provident Fund
EPR	Extended Producer Responsibility
ESI	Employees' State Insurance
EVA	Ethylene-Vinyl Acetate
FLS	Feeder-Level Solarisation
FMEA	Failure Mode and Effects Analysis
FTE	Full-Time Equivalent
GEC	Green Energy Corridor
GW	Gigawatt
HJT	Heterojunction Technology
HR	Human Resources
HSE	Health, Safety and Environment
HVRT	High-Voltage Ride-Through
IEA	International Energy Agency
IGBT	Insulated Gate Bipolar Transistor
IIT	Indian Institute of Technology
ILO	International Labour Organization
IPP	Independent Power Producer
IPQC	In-Process Quality Control
IPS	Individual Pump Solarisation
IQC	Incoming Quality Control
IRENA	International Renewable Energy Agency
ISA	International Solar Alliance
ITI	Industrial Training Institute
KPI	Key Performance Indicator
kWh	kilowatt-hour
LA	Lightning arrester
LOTO	Lockout/Tagout
LVRT	Low-Voltage Ride-Through
MES	Manufacturing Execution System
ML	Machine Learning
MMT	Million metric tons
MNRE	Ministry of New and Renewable Energy
MSDE	Ministry of Skill Development and Entrepreneurship
M.Tech	Master of Technology
MTTR	Mean Time to Repair
MW	Mega Watt
NCVT	National Council for Vocational Training
NISE	National Institute of Solar Energy
NPA	Non-Performing Asset
NSQF	National Skills Qualifications Framework
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
OHS	Occupational Health and Safety
PERC	Passivated Emitter and Rear Cell
PhD	Doctor of Philosophy
PLC	Programmable Logic Controller
PLI	Production Linked Incentive
PM-KU-SUM	Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan
POE	Polyolefin Elastomer
PPE	Personal Protective Equipment
PR	Performance Ratio
PV	Photovoltaic
R&D	Research and Development
RCA	Root Cause Analysis
RTC	Round-the-Clock
SCADA	Supervisory Control and Data Acquisition
SCGJ	Skill Council for Green Jobs
SCM	Supply Chain Management
SDG	Sustainable Development Goals
SPD	Surge Protective Device
TOPcon	Tunnel Oxide Passivated Contact
TW	Tera Watt
UMREPP	Ultra-Mega Renewable Energy Power Park
VET	Vocational Education and Training

Abstract

Solar photovoltaic (PV) technology is central to the clean energy transition in the country.This report examines skill gap assessment covering workforce capabilities, key technological advancements in high-efficiency solar cells, digital monitoring, Artificial Intelligence (AI) and Machine Learning (ML), applications and challenges, emerging skill requirements, and training ecosystem gaps. In India, solar deployment is supported by initiatives such as PM Surya Ghar: Muft Bijli Yojana and the Pradhan Mantri Surya Sarovar Yojana.Addressing challenges in grid integration, indigenous manufacturing, operations and maintenance, and module recycling will require technological innovation, industry-aligned training and a skilled workforce.

The study adopts a five-stage methodology comprising value chain mapping, primary data collection, workforce demand estimation, skill gap assessment, and roadmap development.Primary data is collected through industry surveys and stakeholder consultations to assess workforce composition, skill requirements, recruitment challenges and existing training practices.Workforce demand is projected up to 2030 based on anticipated capacity growth and full-time equivalent (FTE) requirements across the value chain.The study further evaluates existing training programmes, qualification frameworks and institutional infrastructure to identify skill gaps and develop recommendations for strengthening curricula, certification systems and training capacity.

The survey identified specialised skill requirements across the solar value chain, particularly in crystal growth, material science, automation, robotics, quality inspection, and AI/ML-based monitoring. Recruitment relies heavily on ITI, diploma and engineering graduates, who require structured induction and practical training.Training duration and arrangements vary across organisations, while limited access to specialised training infrastructure and workforce attrition of approximately 12-30% remain key challenges.The findings highlight the need for industry-aligned curricula, advanced practical training facilities, and stronger industry-academia collaboration to address emerging skill requirements and strengthen workforce readiness.

By March 2030, India’s solar sector is projected to require approximately 2.71 lakh to 3.68 lakh personnel, comprising 2.16 lakh to 2.87 lakh blue-collar workers and 0.55 lakh to 0.81 lakh white-collar professionals across solar manufacturing and power generation. These projections highlight the need for industry-aligned training programs, specialised skill development, and stronger collaboration between industry, training institutions, and government agencies to support the sector’s expansion.

Executive Summary

India stands at a critical juncture in its national energy transition, committed under its COP26 Panchamrit pledge to achieve 500 GW of non-fossil fuel electricity generation capacity by 2030.Solar photovoltaics (PV) serves as the primary operational engine of this decarbonisation trajectory.Driven by massive interventions-most notably the Solar Parks and Ultra Mega Solar Power Projects scheme for large utility-scale solar projects, PM Surya Ghar: Muft Bijli Yojana targeting 10 million rooftop installations and the PM-KUSUM initiative for agricultural solarisation-India's cumulative installed solar capacity reached 171.05 GW by September 2026.

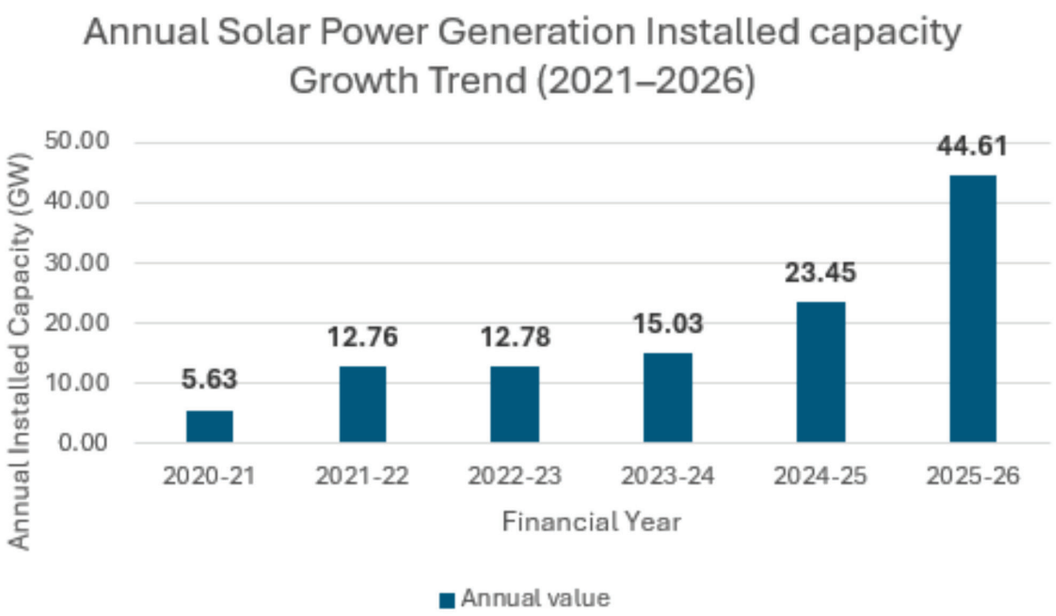


Figure 1: Annual Solar Power Generation Capacity Growth Trend

**Installed Solar capacity as on 31.03.2026 of each financial year (MNRE)*

India's solar PV manufacturing capacity has also expanded significantly over the last four financial years, particularly in the module manufacturing segment.Solar module manufacturing capacity increased from approximately 38 GW/year in FY 2022-23 to 172 GW/year in FY 2025-26, reflecting rapid growth in domestic manufacturing.Solar cell manufacturing capacity has also increased more than four-fold from 6.6 GW/year to 27 GW/year during the same period and is set to reach about 170 GW/year by 2030.In contrast, domestic ingot and wafer manufacturing remains at an early stage, with reported capacity of only 2 GW/year at present, significantly lower than that of modules and cells.It is however, expected to scale up to about 70 GW/year by the year 2030.Though no production facility of polysilicon is commissioned yet, its annual manufacturing capacity is estimated to be about 38 GW/year by the year 2030.

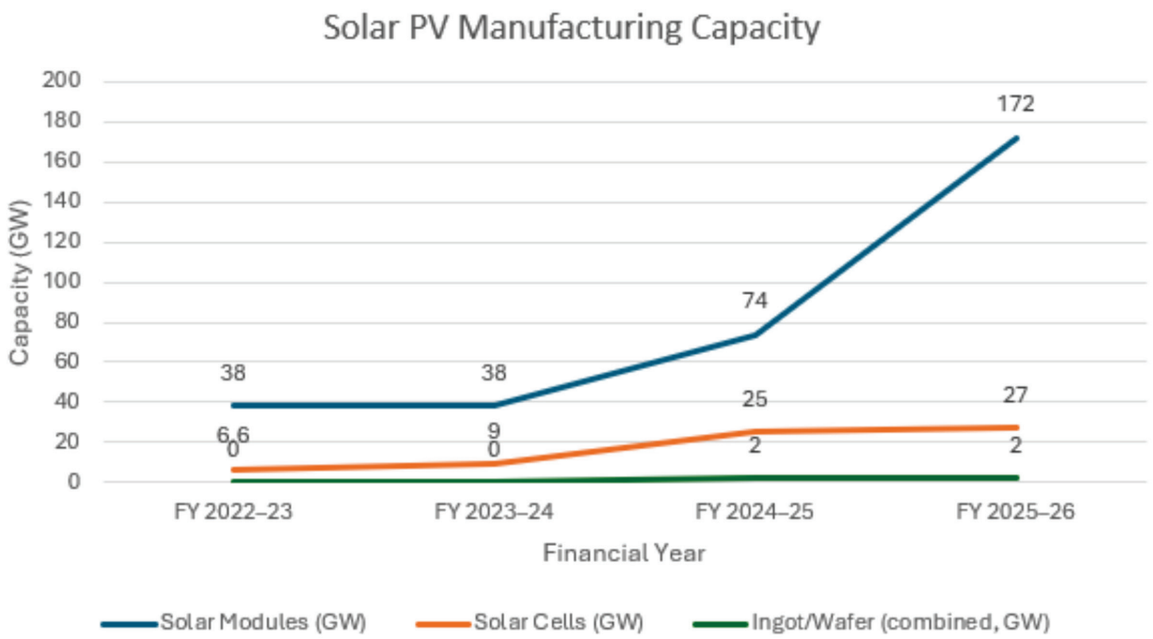


Figure 2: Year-on-Year Growth Trend for Solar PV Manufacturing Value Chain

This rapid capacity scaling across the solar value chain-spanning upstream manufacturing (polysilicon, ingots, wafers, and cells), midstream module assembly, utility-scale EPC execution, and long-term Operations & Maintenance (O&M)-has exposed structural bottlenecks in human capital.Strengthening upstream manufacturing, indigenous machinery production, software development and specialised workforce skills will be essential to building an integrated solar PV manufacturing ecosystem in India. Without targeted intervention, persistent skill deficits threaten project yields, asset reliability, workplace safety, and India's goal of self-reliance in solar energy.

Baseline vs 2030 Workforce Projections (details in Table 12 & Table 20 in Chapter 4)

Between 2026 and 2030, the total solar photovoltaic workforce across manufacturing and power generation is projected to expand by 113% to 118% (averaging approximately 113%), growing from an empirical baseline of 1.50 lakh workforce (ranging across scenarios from 1.24 lakh to 1.76 lakh) to approximately 3.19 lakh workforce (ranging from 2.71 lakh to 3.68 lakh). The growth trajectory diverges sharply between occupational tiers: the blue-collar workforce expands by 100% to 110% (scaling from 1.03 lakh to 1.44 lakh in 2026 to 2.16 lakh to 2.87 lakh personnel by 2030, representing 79% of the total pool). Notably, white-collar professional demand will increase by 154% to 161% (scaling from 21,160 to 31,800 up to 55,210 to 80,750 personnel, averaging 21% of the total pool), driven by backward integration into technologically complex upstream semiconductor processes (polysilicon refining, Czochralski ingot pulling, and cleanroom cell microfabrication), which demand substantial cohorts of specialized process engineers, metallurgists, SCADA integration experts, and quality assurance leads.

Table 1: Comprehensive Workforce Summary Across the Solar Value Chain (Baseline 2026 vs 2030 Projection)*

Sector Segment	Current Capacity (2026)	Projected Capacity (2030)	Current Work-force (2026)	Projected Workforce (2030)	Growth Trajectory & Primary Driver
Solar Manufacturing *(Modules, Cells, Wafers, Polysilicon)*	228 GW (Module), 35 GW (Cell), 2 GW (Ingots & Wafers)	280 GW (Mod), 170 GW (Cell), 70 GW (Ingots & Wafers), 38 GW (Poly Silicon)	53,180 - 75,300 (78% Blue Collar / 22% White Collar)	**1,82,800 - 2,42,800 (75% Blue Collar / 25% White Collar)**	**231%**; Driven by PLI Tranche-II backward integration into n-type TOPCon, HJT, and polysilicon refining
Utility-Scale Generation *(Ground-Mounted & Hybrid - solar component)*	131.01 GWp	200.0 GWp	44,000 - 66,000 (84% Blue Collar and 16% White collar)	**53,000 - 80,000** (83% Blue Collar and 17% White collar)	**30%**; Steady utility park expansions and high-voltage substation grid ties
Decentralized Solar *(Off-grid & PM-KUSUM Component B)*	6.63 GWp	25.0 GWp	2,900 - 4,000 (87% Blue Collar and 13% White collar)	**6,350 - 8,550** (87% Blue Collar and 13% White collar)	**115%**; Acceleration of standalone solar pumps and agricultural feeder solarization
Rooftop Solar (RTS) *(C&I and Residential)*	33.41 GWp	75.0 GWp	24,000 - 30,500 (92% Blue Collar and 8% White collar)	**28,900 - 36,500** (92% Blue Collar and 8% White collar)	**20%**; Surge under PM Surya Ghar: Muft Bijli Yojana across urban/rural rooftops
TOTAL SECTOR FOOTPRINT	**171.05 GWp** *(Gen)* **265 GW** *(Mfg)*	**300 GW** *(Gen)* **558 GW** *(Mfg)*	**1,24,080 - 1,75,800 (82% Blue Collar / 18% White Collar**)	**2,71,050 - 3,67,850 (79% Blue Collar / 21% White Collar)**	**113% Overall Expansion**

** Details are in Table 12 and Table 20 of chapter 4*

Core Insights

The assessment reveals that India's skilling ecosystem suffers from a profound mismatch between traditional vocational training (focused primarily on basic electrical wiring and module assembly) and the advanced semiconductor physics and automation required by modern solar manufacturing and utility operations:

- Upstream Manufacturing Deficits: Ingot pulling (Czochralski CZ furnaces operating at 1,420°C) and diamond-wire wafer slicing suffer from acute shortages of metallurgical and thermal engineers skilled in crystal defect control and kerf-loss reduction.Similarly, domestic polysilicon and cell fabrication lines face severe gaps in handling pyrophoric/hazardous gases (trichlorosilane, Hydrogen, phosphine, HCl etc) and operating high-vacuum PECVD cleanrooms.
- Midstream & Automation Gaps: Fully automated module lines using AI-enabled optical inspection (AOI) and Electroluminescence (EL) testing require technicians skilled in PLC/SCADA programming and machine vision, rather than manual assembly workforce.
- Downstream O&M & EPC Vulnerabilities: Utility-scale EPC execution struggles with high-voltage (220kV/400kV) substation grid compliance, CEA safety standards, and DC arc-fault prevention.In long-term O&M, while robotic dry-cleaning has reduced manual workforce, there is an acute shortage of personnel skilled in radiometric thermography via drones, AI alert validation, and inverter IGBT troubleshooting.
- Institutional Constraints: High employee attrition rates (12% to 30%) across manufacturing plants and remote project sites, combined with a total lack of practical laboratory infrastructure in standard ITIs and polytechnics, force companies to invest heavily in prolonged in-house training (3 to 10 months) before workers become productive.

Strategic Recommendations & Action Plan

To avert execution bottlenecks, a coordinated tripartite roadmap involving Industry, Academic/Training Institutions, and Government/Skill Councils must be executed across clear planning horizons.

Pillar I: Industry Actions

1. Structured Induction & Competency Gateways: Replace ad-hoc 2-day orientations with mandatory 12-day modular induction (behavioural, technical, and safety) backed by rigorous shopfloor competency gates before independent deployment (Timeline: Ongoing/Immediate)
2. OEM-Led Advanced Technical Academies: Establish dedicated in-plant training bays in partnership with machinery OEMs to train technicians on TOPCon/HJT cell tools, automated stringers, and robotic maintenance (Timeline: 0-12 months)
3. Retention & Welfare Infrastructure: Curb 20-30% attrition by offering standardized site allowances, clean hostel accommodations, structured internal promotion pathways, and regional transfer options (Timeline: 0-18 months)

Pillar II: Academic & Training Institution Actions

1. Curriculum Modernization: Overhaul ITI, Diploma, and B.Tech curricula in consultation with senior industry personnel and SCGJ to embed modules on AI/ML in O&M, PVsyst modelling, high-voltage safety, and automation (Timeline: 6-18 months)
2. Establishment of Shared Advanced Labs: Set up Regional Centers of Excellence equipped with solar simulators, IV-curve tracers, and EL testing rigs in collaboration with industrial clusters in all major states where solar manufacturing and power generation projects are located (Timeline: 12 - 36 months)

3. Mandatory Structured Internships: Institutionalize 2-month B.Tech and 6-month M.Tech industry internships with mandatory stipends and pre-approved NDA frameworks for applied research (Timeline: Ongoing)

Pillar III: Government & Skill Council Actions

1. National Solar Workforce Planning Cell: Form a joint MNRE-MSDE task force to monitor state-wise capacity additions and align SCGJ Qualification Packs (QPs) with international IEC standards (Timeline: 0-6 months)
2. Upgradation of Government ITIs: Upgrade training infrastructure in 100 strategic ITIs located near major manufacturing and solar park clusters (Timeline: 12 - 36 months)
3. Recognition of Prior Learning (RPL): Roll out national RPL campaigns under the PM Surya Ghar framework to certify 1,00,000 existing informal solar installation and maintenance workers (Timeline: 0 -24 months)

Implementation Roadmap, Indicative Costs, and Outcome KPIs

To ensure operational accountability, the following matrix outlines the responsible authorities, execution timelines, indicative financial outlays (derived from national skilling benchmarks and GIZ/SCGJ project estimates), and quantitative Key Performance Indicators (KPIs) to measure success.

Table 2: Decision-Oriented Action Matrix, Indicative Costs, and Outcome KPIs

Strategic Action Area	Responsible Authorities & Institutions	Execution Timeline (Months)	Indicative Financial Outlay* (Cost Estimates)	Outcome Measurement & Key Performance Indicators (KPIs)
1.Upgrading ITI & Vocational Lab Infrastructure	MSDE, Directorate General of Training (DGT), State Skill Development Missions, SCGJ	6 to 36	**₹75 crores** (₹75 Lakhs per centre across 100 strategic ITIs for solar simulators, lab benches, and mock-up rooftops)	• Number of upgraded ITIs operational • Annual student enrolment in solar trades • Pass percentage in practical NCVET/ SCGJ assessments
2.Modular Upskilling & RPL Certification *(PM Surya Ghar & Manufacturing)*	SCGJ, National Institute of Solar Energy (NISE), Industry Association Partners	0 to 24	**₹45 crores** (Based on standard skilling benchmarks: ₹3,000 training fee + ₹3,500 candidate stipend per worker for 70,000 workers)	• Number of uncertified workers formally assessed and certified • Percentage transition from informal to formal payroll (EPF/ESI coverage)

Strategic Action Area	Responsible Authorities & Institutions	Execution Timeline (Months)	Indicative Financial Outlay* (Cost Estimates)	Outcome Measurement & Key Performance Indicators (KPIs)
3.Centre of Excellence (CoE) & Advanced Lab Setup *(Upstream Cell/ Ingot/Wafer)*	IITs/NITs, Ministry of Education, State Governments (Gujarat, Telangana, Tamil Nadu, Rajasthan etc.)	12 to 48	**₹120 crores** (₹30 crores per regional CoE equipped with cleanroom training rigs and PECVD/CZ simulation kits)	• Number of joint industry-academia research papers published • Placement rate of postgraduate trainees in upstream manufacturing firms
4.Industry Apprenticeship & Graduate Trainee Subsidy	Ministry of Education, National Apprenticeship Promotion Scheme (NAPS), EPC/ Manufacturing Employers	0 to 48	**₹216 crores** (Stipend co-funding matching NAPS norms of ₹1,500-₹4,500/ month per apprentice for 35,000 trainees)	• Number of active apprentices inducted annually • 1-year post-apprenticeship retention rate within the hiring organization (>75% target)
5.Regulatory Safety & High-Voltage Certification Framework	Central Electricity Authority (CEA), State Electrical Inspectorates, SCGJ	3 to 18	**₹8 crores** (Curriculum design, safety manual drafting, digital examination portal, and inspector training)	• Zero fatal electrical accidents during utility-scale construction • 100% compliance audit closures for CEIG high-voltage substation grid ties
TOTAL ESTIMATED PROGRAMME OUTLAY	**Multi-Stakeholder Consortium**	**2026 - 2030**	**₹464 crores** *(Across a 4-year national implementation window)*	**Sector-Wide Target:** 1.5+ Lakh formally certified professionals deployed, reducing initial plant breakdown rates by 35% and saving an estimated ₹1,600 Cr in avoided energy yields and asset rework over the decade

Note on Indicative Costs (Table 2): The financial outlays (e.g., ITI infrastructure upgrades, training stipends, and CoE establishment costs) were modeled using standard national skilling cost norms under the National Apprenticeship Promotion Scheme (NAPS), Pradhan Mantri Kaushal Vikas Yojana (PMKVY) financial benchmarks, and GIZ technical cooperation project cost templates.

The indicative costs in the above table are estimates.Each strategic action area listed shall be a project in itself and a firm cost estimate should be arrived at the time of its planning and implementation.

Conclusion

Addressing the human capital deficit in India's solar PV sector is no longer optional-it is a pre-condition for fulfilling the 500 GW non-fossil mandate and capturing global market share in advanced solar manufacturing.By committing an estimated ₹464 crores in targeted skilling infrastructure, curriculum reform, and apprenticeship support between 2026 and 2030, India can eliminate execution bottlenecks, enhance plant reliability, formalize over 1.7 lakh green jobs, and establish enduring technological self-reliance.



1.Background

1.1.Introduction

The transition towards sustainable energy has become an important priority due to increasing electricity demand, depletion of conventional resources, and environmental concerns associated with fossil fuel-based power generation.Renewable energy technologies, particularly solar photovoltaic (PV) systems, offer an effective solution for meeting a growing share of electricity demand while reducing greenhouse-gas emissions.India's per capita electricity consumption increased from 1,161 kWh in 2020-21 to 1,460 kWh (approx.) in 2024-25[1], reflecting growing electricity demand driven by economic development, industrialisation, urbanisation, and rising household energy requirements.Solar PV technology converts sunlight directly into electrical energy and can be implemented in systems ranging from small rooftop installations to large utility-scale power plants.Continuous developments in photovoltaic materials, cell structures, module design, and power electronics have improved the efficiency, reliability, and economic performance of PV systems.The integration of PV systems with battery storage, smart inverters, and advanced monitoring systems is further improving their flexibility and reliability.



Figure 3: Ground Mounted Solar PV

Solar PV has also become an important part of India's renewable energy strategy.With favourable solar resources and increasing electricity requirements, India has expanded both utility-scale and distributed solar installations.However, issues such as intermittency, grid integration, transmission capacity, energy storage, indigenous machine manufacturing, software integration and module recycling must be addressed to support continued growth.This report provides an overview of solar PV technology, its development, applications, advantages, limitations, current trends, and prospects.The primary objective of this report is to conduct a comprehensive skill gap assessment.The study evaluates existing workforce capabilities, identifies current and emerging skill requirements, assesses gaps in technical competencies and training infrastructure, and proposes strategic recommendations to develop an industry-ready workforce capable of supporting the sector's sustainable growth.

1.2.Renewable Energy Sector in India

India has emerged as one of the fastest-growing clean energy markets in the world, ranking third globally in total renewable energy installed capacity behind China and the United States.Driven by sustained policy commitments, the country is actively working toward achieving 500 GW of non-fossil fuel capacity by 2030 and net-zero carbon emissions by 2070.[2]

[1] https://cea.nic.in/api/dashboardReports/view-pdf/en/ebe71a40-dca5-451b-9d87-3f45a66b36a7
[2] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2026/Mar/IRENA_DAT_RE_capacity_statistics_2026.pdf

Solar PV remains a cornerstone of India's green growth trajectory, with cumulative installed capacity increasing more than 60 times since 2014, from 2.82 GW in March 2014 to approximately 171.05 GW as of September 2026.Ground-mounted utility-scale solar accounts for a substantial share of the country's installed solar capacity, supported by the development of large-scale solar parks and Ultra Mega Renewable Energy Power Projects (UMREPPs) across states such as Rajasthan, Gujarat, Karnataka and Andhra Pradesh.[3]

India's updated Nationally Determined Contribution (NDC), approved in August 2022, raised the target for non-fossil fuel-based installed electric power capacity from 40% to 50% by 2030, reinforcing its commitment to clean energy and climate action.

In June 2025, India achieved the 50% non-fossil installed capacity milestone, more than five years ahead of schedule, marking significant progress in its energy transition.Separately, the country continues to pursue its COP26 Panchamrit commitment of achieving 500 GW of non-fossil fuel-based installed capacity by 2030.[4]

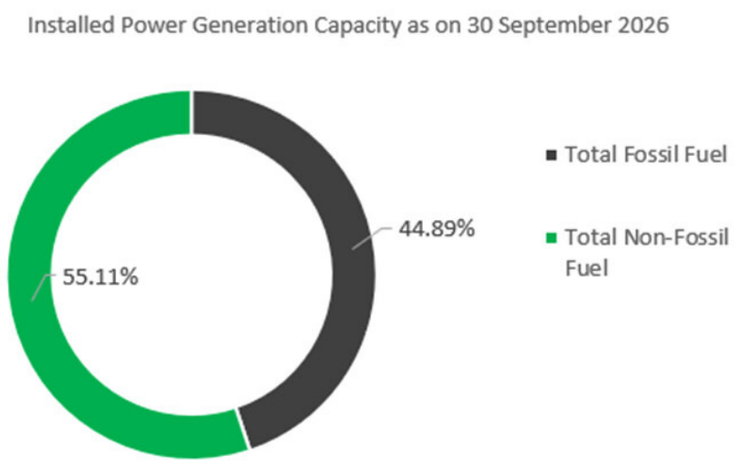


Figure 4: Source wise Installed Power Generation Capacity Mix (30 September 2026) [5]

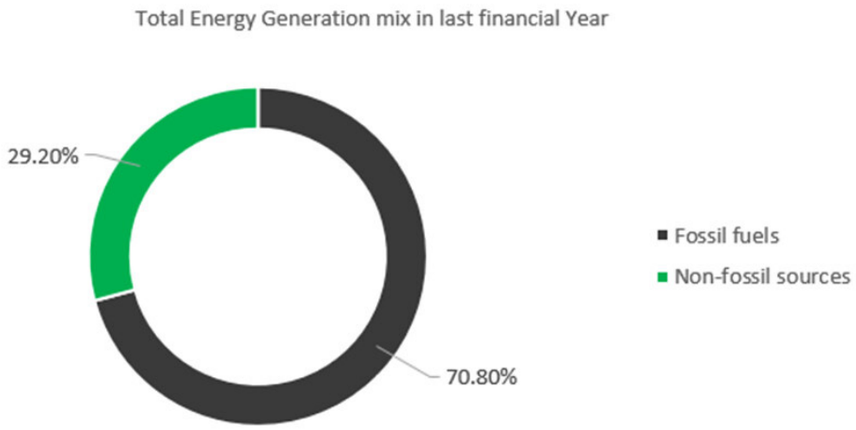


Figure 5: Share of fossils and non-fossils in total energy generation for last fiscal year (2025 - 26) [6]

[3] https://mnre.gov.in/en/physical-progress/
[4] https://sansad.in/getFile/annex/268/AS16_b4Lf4f.pdf?source=pqars
[5] https://cea.nic.in/reports/dashboardView?headingId=107&subHeadingId=1003&subSubHeadingId=10014&title=Installed%20Capacity&lang=en
[6] MNRE post- India reached its highest-ever renewable energy share in electricity generation: Shri Joshi Posted On: 08 APR 2026 4:17PM by PIB Delhi

Composition of India's Non-Fossil installed capacity Portfolio

As illustrated in the figure 4, India's non-fossil fuel capacity portfolio which has surpassed 300 GW and accounts for more than 55.11% of the country's aggregate installed capacity base exhibits a pronounced concentration in Variable Renewable Energy (VRE) sources.Solar photovoltaic (PV) technology constitutes the single largest component, representing 170GW of the total clean energy capacity.This structural profile underscores that while solar expansion remains the primary volume driver of India's clean energy growth, achieving resilient round-the-clock (RTC) power will fundamentally depend on co-locating multi-hour energy storage (BESS) and scaling dispatchable non-fossil balancing mechanisms.[7]

The electricity generation mix indicates that fossil fuels account for 70.80% of total generation, amounting to 1,306.95 BU, while non-fossil sources contribute 29.20%, equivalent to 538.97 BU.The higher share of fossil fuels reflects India's continued dependence on coal-based power generation to meet its large and growing electricity demand, supported by established generation infrastructure and its role in providing reliable, dispatchable power.In comparison, the contribution of non-fossil sources, including solar, wind, hydro, and nuclear energy, reflects the ongoing diversification of the power mix. However, the variable nature of solar and wind generation, along with the need for adequate energy storage, transmission infrastructure and grid-balancing capabilities, influences the pace at which renewable energy can be integrated into the electricity system.

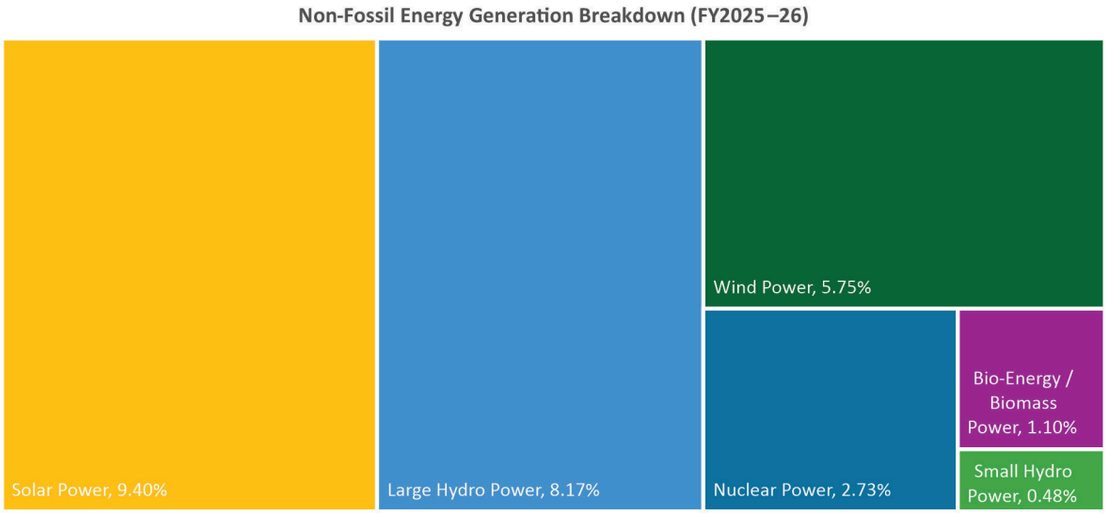


Figure 6: Non-Fossill Energy Generation Breakdown(FY2025 - 26)

In FY 2025-26, India's renewable energy sector witnessed significant growth, with combined solar and wind power generation reaching 276.61 BU, accounting for 15.14% of total national electricity generation.The country also recorded a substantial expansion in non-fossil energy capacity, adding a record 55.29 GW during the year, compared with 29.5 GW in FY 2024-25.This accelerated addition of non-fossil capacity reflects the increasing contribution of clean energy sources to India's electricity mix.

[7] https://cea.nic.in/api/dashboardReports/view-pdf/en/44e85015-7b5d-42c8-ae91-f34e15cd9708

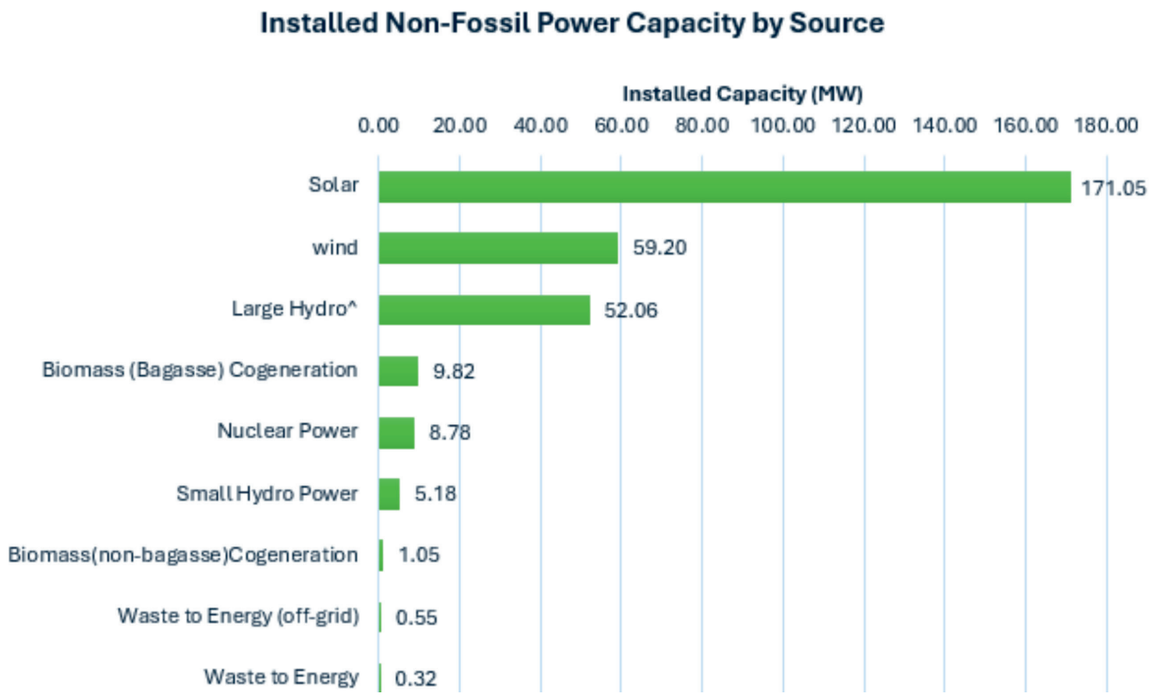


Figure 7: Source wise Installed capacity for non-Fossil

**Large Hydro includes 7.4256 GW Pumped Storage*
**As of 30.09.2026*

Solar energy alone accounts for approximately 55.5% of the total capacity across the listed sources, highlighting its significant contribution to the country's energy transition.Other technologies, including nuclear power, biomass cogeneration, small hydropower and waste-to-energy, provide additional diversification to the energy mix.The continued expansion of solar capacity underscores the need for a skilled workforce across manufacturing, project development, installation, commissioning, operations and maintenance.

1.2.1. Key Growth Drivers & Policy Frameworks



Figure 8: Key Growth Drivers & Policy Frameworks

Key drivers for accelerating solar adoption are as follows:

1. National Policy Push: PM Surya Ghar: Muft Bijli Yojana targets 10 million residential rooftop solar installations, radically shifting generation to decentralised urban and rural rooftops.
2. Production Linked Incentive (PLI) Scheme: Fostering domestic manufacturing across solar PV modules, cells, ingots, and wafers to reduce foreign import reliance under the Approved List of Models and Manufacturers (ALMM).
3. Green Energy Corridors (GEC): Inter-state and intra-state high-voltage transmission networks built specifically to evacuate power from resource-rich renewable zones to demand hubs.
4. Shift Toward Round-The-Clock (RTC) & Hybrid Systems: Tariff-based competitive bidding has transitioned from solar/wind tenders to Wind-Solar Hybrid and RTC tenders backed by Battery Energy Storage Systems (BESS) and pumped storage projects (PSP).
5. Floating, Agricultural Solar & Green Hydrogen Missions: Deployment of agricultural solar pumps via PM-KUSUM, development of floating solar systems (such as the PM Surya Sarovar initiative), and the National Green Hydrogen Mission targeting 5 MMT annual production by 2030.[8]
6. Global Commitments and International Climate Goals: Global initiatives such as the Paris Agreement, the United Nations Sustainable Development Goals (SDG 7 and SDG 13), and the COP28 commitment to triple global renewable energy capacity to at least 11 TW by 2030 are accelerating the transition towards clean energy.These encourage countries to expand renewable energy deployment, strengthen energy security, promote technological innovation, and develop skilled workforce to support the global energy transition.
7. Voluntary Industry Decarbonisation Initiatives: Growing corporate participation in initiatives such as RE100, commitments towards net-zero emissions and voluntary greenhouse gas emission reduction targets are accelerating renewable energy adoption, promoting sustainable industrial practices and supporting the transition towards a low-carbon economy.
8. Adoption of Green Product Certifications and Rating Systems: Increasing adoption of green product certifications, sustainability rating systems and environmental performance standards across industries is promoting renewable energy utilisation, resource efficiency, sustainable manufacturing practices and the transition towards low-carbon operations.
9. Renewable Consumption Obligation (RCO) and Regulatory Measures: Renewable Consumption Obligation targets notified under the Energy Conservation Act framework, Carbon Credit Trading Scheme (CCTS), Green Energy Open Access Rules and associated government schemes, are strengthening regulatory support for renewable energy procurement and consumption across designated consumers and other obligated entities.

1.2.2. Structural Bottlenecks

While financial capital flows and statutory support remain robust, the renewable energy sector faces operational constraints:

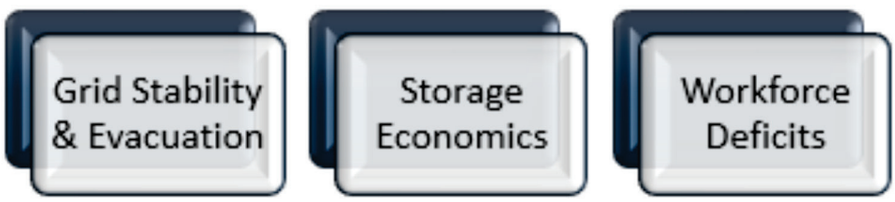


Figure 9: Structural Bottlenecks

[8] https://www.pib.gov.in/PressReleasePage.aspx?PRID=2292433&reg=48&lang=1

1. Grid Stability & Evacuation: High curtailment risks and transmission congestion during peak solar generation hours.
2. Storage Economics: Capital costs and supply chain constraints associated with scaling grid-scale lithium-ion and sodium-ion BESS.
3. Workforce Deficits: Rapid technological advancements, including the transition from PERC to n-type TOPCon and HJT technologies, SCADA-enabled digital substations, and automated string monitoring, have outpaced conventional technical training programs. Furthermore, Domestic Content Requirement (DCR) provisions and policy-driven domestic manufacturing initiatives are encouraging the development of indigenous solar PV manufacturing capabilities, reducing dependence on imported components and creating demand for skills in backward integration, particularly across polysilicon, ingot, wafer, and cell manufacturing.However, as these manufacturing segments are still developing in India, the availability of an industry-ready workforce with specialised technical expertise remains limited, highlighting the need for targeted upskilling, advanced technical training, and industry-academia collaboration.

1.2.3. Key Structural, Grid, and Operational Challenges



Figure 10: Structural Challenges

1. Grid Integration and Curtailment Vulnerabilities: Solar generation peaks precisely between 11: 00 AM and 2: 00 PM, creating a severe net-load deficit followed by a steep evening ramp when solar generation drops to zero just as domestic residential demand surges.Managing this “duck curve” without synchronous rotational inertia requires high-voltage dynamic reactive power compensation and battery storage.In resource-dense zones, transmission bottlenecks periodically force local load dispatch centres to curtail renewable energy generation
2. Financial Health of Distribution Companies (DISCOMs): Sub-national distribution utilities remain the weakest financial link in the power ecosystem.Legacy of structural debts, delayed subsidy disbursements, and high Aggregate Technical and Commercial (AT&C) losses impair their cash-flow solvency.This fiscal stress often leads to delayed payments to independent power producers (IPPs), disputes over contractual curtailment compensation, and institutional reluctance to facilitate commercial and industrial open access.
3. Land Acquisition and Environmental Concerns: Large-scale utility solar installations require between 3.5 to 5 acres of land per megawatt capacity.Acquiring contiguous, litigation-free land parcels across states like Rajasthan, Gujarat, and Karnataka frequently leads to project execution delays.Furthermore, the construction of the Green Energy Transmission Corridors across Western India has encountered environmental and judicial constraints, most notably the Supreme Court mandates to protect the endangered Great Indian Bustard (GIB) by undergrounding overhead high-voltage transmission lines.

1.3.Strategic Roadmap Towards 2030

To scale non-fossil capacity to 500 GW by 2030 and build a secure, net-zero power architecture, policy and industry focus is centred on four operational imperatives.



Figure 11: Strategic Roadmap for achieving 500 GW non fossil by 2030

1. Storage Parity and Mandates: Enforcing Energy Storage Obligations (ESO) on state utilities and industrial entities to accelerate the procurement of Battery Energy Storage Systems (BESS) and Pumped Storage Hydro is important. Developing indigenous sodium-ion and iron-flow battery chemistries alongside lithium-ion supply chains will be critical to lowering storage costs.
2. National Green Hydrogen Mission: Target production of 5 million metric tons (MMT) of green hydrogen annually by 2030, anchored by localised electrolyser manufacturing incentives and dedicated renewable power generation parks.Green hydrogen will serve as the primary decarbonization mechanism for heavy industry, fertilisers, and refining.
3. Modernisation of the Transmission Highway: Accelerated commissioning of Phase-II of the Green Energy Corridors (GEC) and High-Voltage Direct Current (HVDC) interstate transmission networks to connect Western and Northern renewable-rich pockets with major Southern and Eastern industrial demand centres.[9]
4. Circularity and Life-Cycle Management: Implementing stringent Extended Producer Responsibility (EPR) regulations under national e-waste management frameworks to ensure systematic collection, silver/silicon recovery, and recycling of decommissioned solar PV panels.[10]

India's renewable energy sector has evolved from a policy-driven niche into a commercially competitive market driver of national electricity growth.Surpassing 53% non-fossil capacity reflects strong public-sector direction and private capital mobilisation.The next phase of India's energy transition will depend not merely on adding gross solar and wind capacity, but on systems integration: expanding grid-scale storage, ensuring the financial solvency of distribution networks, modernising transmission corridors, and building resilient domestic supply chains.Addressing these structural factors will enable India to maintain energy sovereignty, sustain economic development, and provide a viable template for the global clean energy transition.

1.4. Need for skill gap assessment

Skill gap assessment is a systematic process of identifying the difference between the existing skills of the workforce and the skills required to perform specific jobs effectively.In the solar sector, it involves examining the technical, managerial, digital, safety, and operational skills needed for different occupations such as solar PV design and engineering, installers, electricians, technicians, site supervisors, engineers, project managers, and maintenance workforce.

[9] https://www.cercind.gov.in/regulations/175-Notification.pdf
[10] https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=1906920&reg=48&lang=2

1.4.1 Technological Transition Across the Solar Lifecycle

Table 3: Technological Transition Across the Solar Utility Scale plants

Project Lifecycle Phase	Evolving Technical Frontier	Identified Workforce & Skill Deficiencies
System Engineering & Design	Transition from fixed-tilt PERC to bifacial n-type Topcon/HJT modules paired with dynamic BESS	Deficits in advanced 3D shading simulations, bifacial albedo modelling, DC: AC oversizing optimisation, and battery cycle degradation calculations
Construction & Commissioning	High-voltage transmission substation grid ties	Improper cable crimping, torque calibration errors, lack of DC arc-fault protection expertise, and risks of non-compliance with CEA grid connectivity standards
Operations & Maintenance (O&M)	Transition from calendar-based reactive maintenance to automated, predictive diagnostics[11]	Lack of trained workforce for drone-based radiometric thermography, automated IV-curve tracing, inverter IGBT component troubleshooting, and SCADA alarm analytics
Circularity & Module Recycling	Emerging Extended Producer Responsibility (EPR) mandates under national e-waste regulations	Inadequate technical expertise in safe high-voltage module decommissioning, delamination, and hazardous material recovery (e.g., silver, lead, silicon)

Table 4: Technological Transition Across Solar Manufacturing

Manufacturing Segment	Evolving Technical Frontier	India's Current Position	Identified Workforce and Skill Deficiencies
Solar Module Manufacturing	Transition from PERC to n-type TOPCon, HJT and back-contact technologies; advanced tabber-stringer systems, automated optical inspection (AOI), machine vision and AI-enabled quality control	India has an established module manufacturing base, also with advanced automation and specialised equipment capabilities are integrated	Shortages in advanced machine operation, equipment calibration, EL image analysis, AI-based defect detection, yield optimisation, PLC integration, machine-vision software and manufacturing execution systems (MES)

[11] https://solarbestpractices.com/src/Frontend/Files/MediaLibrary/11/o-and-m-best-practice-guidelines-v-5-0-a07c44238b.pdf

Manufacturing Segment	Evolving Technical Frontier	India's Current Position	Identified Workforce and Skill Deficiencies
Solar Cell Manufacturing	Advanced cell architectures such as TOPCon, HJT and back-contact cells; improvements in surface passivation, diffusion, deposition, laser processing and metallisation	Domestic cell manufacturing is expanding, but dependence on imported high-end fabrication equipment and specialised process technologies remains a challenge	Skill gaps in semiconductor processing, cleanroom operations, diffusion and deposition, chemical handling, defect analysis, cell characterisation, process integration, equipment control software and R&D
Solar Wafer Manufacturing	Thinner wafers, advanced diamond-wire slicing, reduced kerf loss, improved wafer yield, precision surface treatment, and automated inspection	Domestic wafer manufacturing capability remains limited, with substantial dependence on imported wafering equipment and specialised process technologies	Skill gaps in precision machinery operation, wire-saw control, wafer thickness and flatness measurement, breakage reduction, surface-defect analysis, equipment software, sensor integration, and predictive maintenance
Solar Ingot Manufacturing	High-purity crystalline silicon ingot production; advanced crystal growth, directional solidification, thermal management and impurity control	Domestic industrial-scale capability remains limited relative to downstream manufacturing, with significant dependence on imported production equipment and associated technologies	Shortages in crystal growth, furnace operation, thermal modelling, crystallographic analysis, impurity control, process optimisation, indigenous furnace design, automation and proprietary equipment-control systems
Polysilicon Manufacturing	Production of solar-grade, high-purity polysilicon using the Siemens process and alternative purification technologies; advanced chemical processing, deposition and energy optimisation	This is a major upstream capability gap for India. Commercial-scale domestic production and the supporting specialised equipment ecosystem remain limited	Shortages in chemical engineering, high-purity material processing, reactor operation, gas handling, contamination control, analytical chemistry, process safety, purification systems, process-control software, and commercial-scale plant operations

Table 5: Crosscutting Skill Gaps and Capacity-Building Recommendations for India's Solar PV Manufacturing Value Chain

Cross-cutting Area	Identified Gap in India	Recommended Skill and Capability Development
Indigenous Machinery Manufacturing	Dependence on imported equipment for advanced cell fabrication, ingot growth, wafer slicing and polysilicon production	Develop domestic machine design capabilities, precision engineering, industrial automation, equipment commissioning, calibration and troubleshooting
Industrial Software and Process Control	Dependence on proprietary equipment software and external suppliers for specialised upgrades and troubleshooting	Develop skills in PLC/SCADA, MES, machine vision, AI-based defect detection, digital twins, process analytics and predictive maintenance
Process Engineering and R&D	Limited experience in scaling advanced manufacturing processes and stabilising new production lines	Establish industry-academia R&D programmes, pilot facilities, process-characterisation laboratories and specialised.research projects
Equipment Commissioning and Plant Stabilisation	Dependence on external equipment suppliers during installation, ramp-up and performance optimisation	Provide practical training in installation, commissioning, process recipes, equipment reliability, yield improvement and root-cause analysis
Specialised Workforce Development	Shortages of experienced professionals in semiconductor processing, crystal growth, chemical purification, precision manufacturing and automation	Introduce specialised curricula and hands-on training through ITIs, polytechnics, engineering institutions and industry-led training centres
Academia-Industry Collaboration	Limited collaboration between industry and academic institutions in curriculum development, applied research, advanced laboratory infrastructure and practical training.Insufficient industry exposure for students and limited access to industrial-grade equipment, manufacturing processes and real-world problem statements may affect industry readiness	Establish structured industry-academia partnerships for curriculum revision, joint R&D, advanced laboratory development and equipment-based training.Industry should provide internships, live project assignments, research problem statements, industry expert lectures and access to relevant equipment.Faculty development programmes and collaborative M.Tech/ Ph.D.research should be promoted to strengthen industry-relevant skills across module, cell, ingot, wafer and polysilicon manufacturing

1.4.2. The Decentralised Rooftop Surge

The launch of the PM Surya Ghar: Muft Bijli Yojana, which targets rooftop solar installations across 10 million households, has shifted the demand for technical talent from centralised desert solar parks directly into urban and rural residential neighborhoods[12].

Residential rooftop installations introduce unique operational and safety complexities:

1. Structural Assessments: Field technicians must evaluate diverse building structures, rooftop masonry, and regional wind-load tolerances to prevent structural failures.
2. High-Voltage Domestic Hazards: Rooftop DC cables operate under continuous exposure to UV radiation and thermal cycling.Improper installations heighten the risk of self-sustaining DC electrical arcs and residential fires.
3. Earthing and Electrical Bonding: Improper earthing of PV modules, mounting structures, inverters, and associated electrical equipment can increase the risk of electric shock and equipment damage.Technicians must possess adequate knowledge of earthing system design, equipotential bonding, earth resistance measurement, and electrical safety compliance.
4. Lightning Protection and Surge Protection: Inadequate lightning protection and improper installation of lightning arrestors (LA) and surge protection devices (SPDs) can expose rooftop PV systems to transient overvoltage and equipment failures.Workforces require specialised competencies in lightning risk assessment, protection system design, installation, and periodic inspection.
5. Engineering and System Design: Inadequate system sizing, improper inverter selection, incorrect string configuration, shading assessment errors, and insufficient consideration of roof orientation and structural constraints can compromise system efficiency and safety. Skilled workforce is required for electrical design, layout optimisation, load calculations, protection coordination, and compliance with applicable technical standards.
6. Working at Heights and Fall Protection: Rooftop installations involve significant risks associated with working on elevated, inclined, or fragile surfaces.Inadequate fall protection, unsafe ladder access, and improper handling of modules can result in serious accidents. Technicians must be trained in personal protective equipment (PPE), fall-arrest systems, safe access procedures, and emergency rescue protocols.

1.4.3. Socio-Economic, Financial Risks

Neglecting a skill gap assessment produces cascading risks across the renewable energy value chain:

1. Asset Underperformance and Financial Default: Suboptimal engineering practices and inadequate maintenance can result in solar power generation falling below projected estimates, affecting project revenues and long-term financial viability.Persistent generation shortfalls over a typical 25-year project lifecycle may weaken Debt Service Coverage Ratios (DSCR) and increase financial risks for lenders.This highlights the importance of skilled professionals in project design, installation, commissioning, performance monitoring and operations and maintenance to ensure optimal plant performance and asset reliability.[13]
2. Workplace Safety Liabilities: Deficiencies in personal protective equipment (PPE) protocols, elevated fall protection, and high-voltage DC safety directly leads to electrical flashover injuries, falls from heights, and avoidable fatalities

[12] https://mnre.gov.in/en/notice/operational-guidelines-for-implementation-of-the-component-central-financial-assistance-to-residential-consumers-of-pm-surya-ghar-muft-bijli-yojana/
[13] https://www.careratings.com/upload/pdf/get-rated/Rating-Methodology-Solar-Power-Projects-December-2024.pdf

3. Grid Destabilisation: Poorly configured power electronics, inaccurate inverter ride-through (LVRT/HVRT) settings, and lagging harmonics compliance introduce power-quality disturbances and grid instability [14]

4. Impediments to a Just Transition: As India progressively modernises its energy sector and diversifies away from regional coal reliance, the green economy must deliver high-quality, high-wage local employment.Without structured reskilling frameworks, workers and communities in legacy energy corridors will be excluded from the clean energy transition

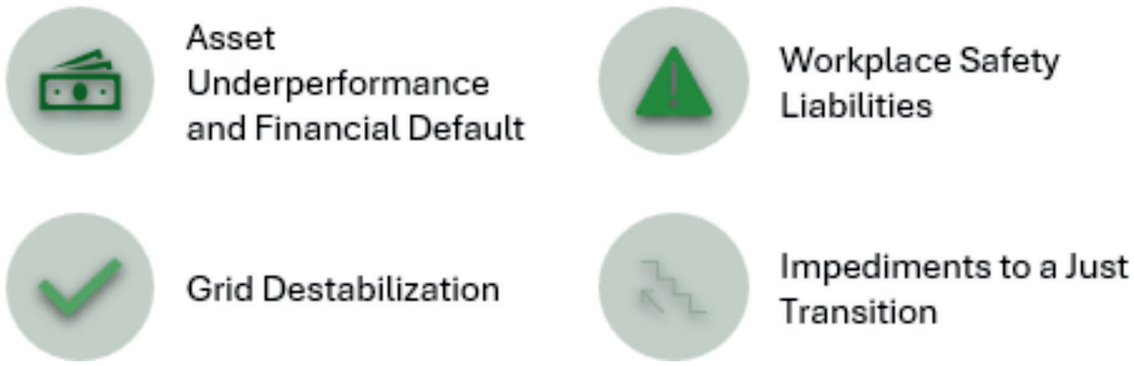


Figure 12: Socio-Economic Financial Risks

Conducting a rigorous skill gap assessment provides the empirical foundation necessary to align academic curricula, create industry-standardized micro-credentials, and deploy a certified technical workforce capable of supporting India's 2030 clean energy targets.

1.5. Objectives of the study



Figure 13: Objectives of the study

To accomplish this goal, the research is organised into six core objectives:

1. Map the Existing Workforce Footprint Across the Solar Value Chain:

   - Quantify current direct and indirect employment across manufacturing, engineering design, EPC execution, grid integration, and lifecycle operations & maintenance (O&M).
   - Disaggregate the workforce force across three functional tiers: Strategic/Engineering (analysts, engineers), Supervisory/Commissioning (site quality leads, substation engineers), and Field Execution (certified technicians, wiremen, racking installer).

[14] https://cea.nic.in/regulations-category/connectivity-to-the-grid/?lang=en

2. Identify and Characterise Critical Competency Deficits Across Technology Frontiers:

   - Pinpoint knowledge and operational voids from advanced technologies, including n-type cell architectures (Topcon, HJT), Balance-of-system (BOS) components, and single-axis tracker algorithms.

3. Audit Institutional Training Infrastructure and Curricular Efficacy:

   - Benchmark public and private training frameworks (including ITI trades, the Surya Mitra Skill Development Program, and Skill Council for Green Jobs qualification packs) against real-world EPC job requirements.

   - Evaluate the physical training infrastructure, laboratory test benches, and institutional lead time required to integrate emerging technology standards into accredited curricula.

4. Analyze Regional Disparities, Labor Mobility, and Health & Safety Standards:

   - Identify geographic mismatches between talent-generating hubs and resource-rich solar zones (e.g., Rajasthan, Gujarat, Karnataka, Andhra Pradesh, Maharashtra).

   - Assess occupational health and safety (OHS) compliance, focusing on high-voltage DC arc-fault risks, working-at-height fall arrest systems, and DISCOM line-worker protection against anti-islanding hazards.

5. Formulate a Strategic Roadmap:

   - Develop structured recommendations for industry-academia partnerships connecting solar EPC developers, module/inverter OEMs, and vocational bodies.

6. Academic Institutions and Industry-Academia Collaboration:

   - Evaluate the existing academic ecosystem to assess the alignment of academic curricula with emerging industry requirements across the solar value chain.

   - Evaluate the effectiveness of industry-academia partnerships, collaborative R&D initiatives in enhancing practical exposure, strengthening technical competencies, and improving graduate employability in line with evolving solar industry requirements.



2.Industry Overview

2.1.Solar Energy Sector

The global solar photovoltaic (PV) sector has crossed the multi-terawatt operational threshold, cementing its position as the fastest-growing power-generation source in history.Driven by the global consensus established at COP28 to triple global renewable energy capacity by 2030, solar PV accounts for major share of all newly added generation assets worldwide.The International Renewable Energy Agency (IRENA) estimates that sustained average annual global renewable power capacity additions of approximately 1,044 GW, including 578 GW of solar PV, are required during 2024-2030 to remain aligned with a 1.5°C climate pathway.[15]

This global transition is marked by a profound structural paradox: the physical demand for solar power is globally dispersed across continents, but the industrial and technological capacity to produce solar hardware remains concentrated in a singular geographic hub.

The operational challenge has shifted from basic technology validation and capital attraction to complex industrial supply chain resilience, grid accommodation and the availability of specialised technical human capital.As the sector transitions to co-located Battery Energy Storage Systems (BESS), the absence of a uniformly qualified international technical workforce force has emerged as a primary constraint on asset reliability and project yields globally.

According to the IEA's Global Energy Review, solar PV has transitioned from an alternative energy source to the primary engine of global energy supply expansion.Solar PV represented the largest single source of growth by meeting more than 25% of all new incremental energy demand worldwide[16].

Table 6: Global Cumulative Solar PV Installed Capacity[17]

Country	Cumulative Solar PV Installed Capacity (GW) as on year
China	1243.6
United States of America	224.8
India	171.05
Germany	110.5
Japan	94.8
Brazil	68.2
Spain	49.4
Australia	43.1
Italy	43
France	32.6
South Korea	31.8
Netherlands	26.9
Poland	26.1
Vietnam	19.8

[15] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Nov/IRENA_World_energy_transitions_outlook_2024.pdf
[16] https://iea.blob.core.windows.net/assets/df903e1c-49c6-4757-8cbf-6fbcfe7611a0/GlobalEnergyReview2026.pdf
[17] Data has been captured from different websites of different countries

The data highlights the widespread adoption of solar energy across major global markets, including China, the United States, Germany, Brazil, Spain, Japan, Australia, and Italy.While China leads in installed solar capacity, other developed and emerging economies are also expanding their solar infrastructure, reflecting growing investments, supportive policy frameworks, and increasing commitments towards clean energy transitions worldwide.

The increasing deployment of solar energy technologies has created a growing requirement for workforce possessing appropriate technical, operational, digital and safety-related competencies.Consequently, understanding the technological development and applications of solar energy provides an important foundation for examining the skill requirements and skill gaps within the sector.

The expansion of the solar sector also has important implications for employment and workforce development.IRENA and the International Workforce Organization (ILO) estimated that the global renewable energy sector employed at least 16.6 million people in 2024, with solar PV accounting for approximately 7.2 million jobs, making it the largest renewable-energy employment segment.[18]

Therefore, solar energy development should be considered not only from the perspective of installed capacity and electricity generation but also in terms of the workforce, occupational profiles and competencies required to manufacture, design, install, operate and maintain solar-energy systems.

2.1.1. Solar Energy Resource and Potential

India has significant solar-energy potential because of its geographical location and high solar resource. According to the Ministry of New and Renewable Energy (MNRE), most parts of India receive 250-300 sunny days per year, while annual solar radiation is 1,600-2,200 kWh/m^2.[19]

As of 30 September 2026, India's cumulative installed solar capacity stood at approximately 171.05 GW, comprising ground-mounted solar, grid-connected rooftop solar, hybrid projects with a solar component and off-grid solar systems.Ground-mounted solar accounted for approximately 125.65 GW and grid-connected rooftop solar for approximately 33.41 GW.

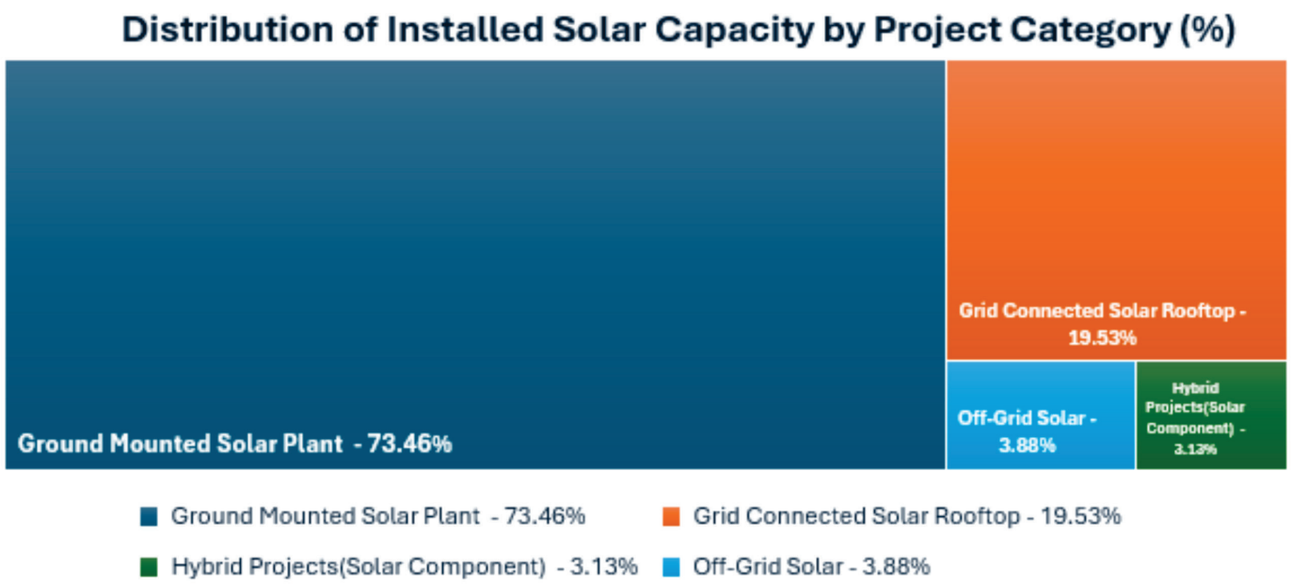


Figure 14: Solar Installed Capacity Distribution by Project Category (%)

**Capacity in GW as on (30.09.2026)*

[18] https://www.irena.org/Publications/2026/Jan/Renewable-energy-and-jobs-Annual-review-2025
[19] https://mnre.gov.in/en/solar-rpo-and-rec-framework/

2.1.2. Key Structural Challenges

1. Intermittency and the “Duck Curve”: Solar generation peaks around midday and drops to zero at sunset just as evening residential demand surges.This requires fast-ramping resources and co-located Battery Energy Storage Systems (BESS) or Pumped Hydro Storage to shift excess daytime solar power into the evening.
2. Transmission & Land Constraints: Mega solar farms require contiguous land (3.5 to 5 acres per megawatt) and substantial investments in high-voltage evacuation networks (such as dedicated Green Energy Corridors).

2.1.3. Solar and India’s Electricity Demand

Solar PV is expected to play a significant role in meeting this demand.The IEA estimates that 50% of India’s additional electricity demand through 2030 could be met by solar PV, while solar generation is forecast to grow at an average annual rate of approximately 24%.[20]

India’s electricity demand is expected to continue growing strongly through the end of the decade.The IEA forecasts average annual electricity-demand growth of approximately 6.4% in India through 2030.

The projected growth reinforces the importance of solar not only as a renewable-energy technology but also as a major contributor to India’s future electricity supply.

2.1.4. The Technology Landscape

The technology landscape of solar PV has evolved over the past decade.Cell and module architecture continue to evolve towards higher efficiency.The industry has progressively moved through technologies such as PERC towards newer architectures including Topcon, heterojunction and back-contact technologies.These developments are aimed at improving conversion efficiency, reducing losses and increasing energy yield.

Technology developments:

1. High-efficiency cell technologies: TOPCon, HJT and back-contact architecture are increasingly relevant to new PV deployment and manufacturing.
2. Bifacial modules: These modules can generate electricity from both sides of the module and can improve energy yield under suitable site conditions.
3. Tracking systems: Single-axis trackers can increase solar-energy capture by adjusting module orientation throughout the day.
4. Larger-format modules: Increasing module size and power output can influence project layout, installation practices, transportation and balance-of-system requirements.
5. Floating PV: Floating systems provide an alternative deployment option for suitable water bodies.
6. Agrivoltaics: These systems integrate solar generation with agricultural activities and require consideration of both energy and agricultural requirements.
7. Solar-plus-storage: Integration of PV with battery storage is becoming increasingly relevant as renewable penetration increases.

The increasing technological diversity of solar systems is creating demand for specialised technical knowledge and multidisciplinary capabilities.

[20] https://mnre.gov.in/en/solar-rpo-and-rec-framework/

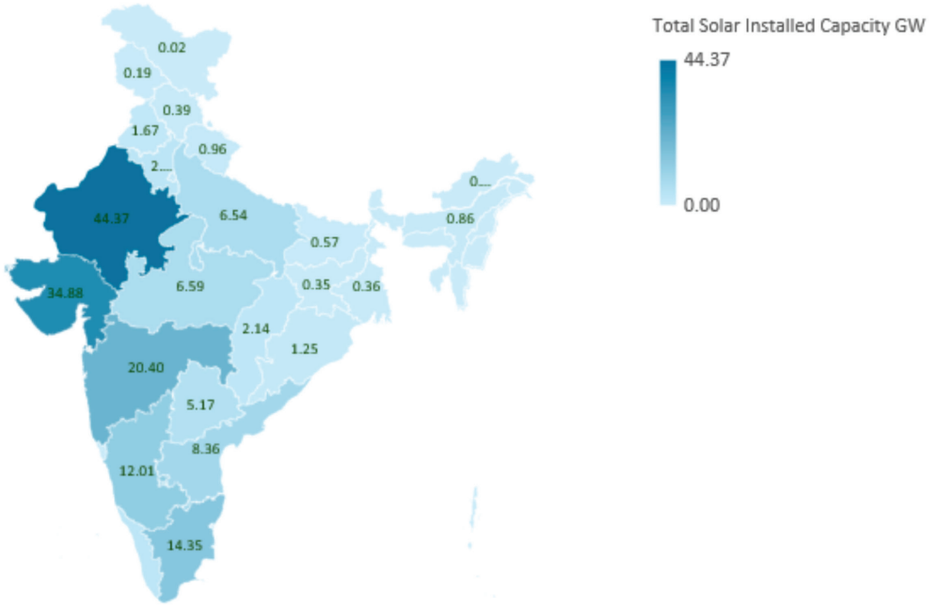


Figure 15: State wise Installed Solar Capacity

2.1.5. Solar Deployment Segments

India's solar market comprises several distinct deployment segments.These segments differ in terms of scale, system design, customers, regulations, operating conditions and workforce requirements.

1.Utility-Scale Solar

Utility-scale solar remains the largest deployment segment in India.Large projects are connected to transmission or distribution networks and may range from tens of megawatts to multi-gigawatt developments.

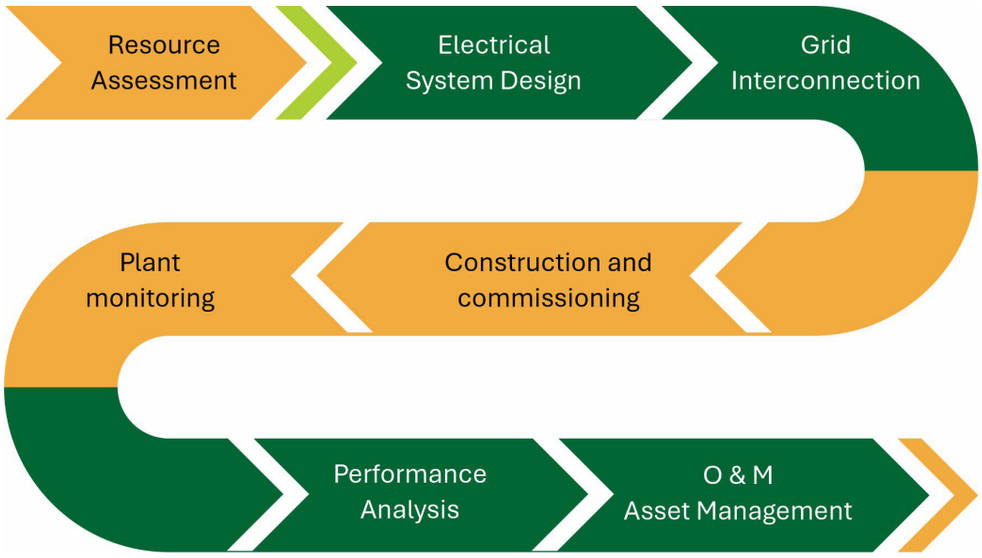


Figure 16: Utility Scale Solar

The increasing scale of utility projects also increases the importance of digital monitoring, predictive maintenance and performance optimisation.

2.Rooftop Solar

Rooftop solar enables electricity generation close to the point of consumption and is applicable to residential, commercial, institutional and industrial buildings.

The Government of India has supported rooftop deployment through the Grid Connected Rooftop Solar Program and the PM-Surya Ghar: Muft Bijli Yojana.The earlier Grid Connected Rooftop Solar Program targeted cumulative rooftop capacity of 40 GW.The program's Phase-II period extended up to 31 March 2026, with central financial assistance provided to eligible residential consumers.[21]



Figure 17: Rooftop Solar

3.Commercial and Industrial Solar

Commercial and industrial consumers represent an important segment of India's solar market.

Solar deployment in this segment can involve:



Figure 18: Commercial and Industrial solar

The segment requires professionals who understand not only PV systems but also electricity consumption patterns, tariffs, contracts, regulatory requirements, energy accounting and commercial considerations.

4.Agricultural Solar

Agricultural applications represent another critical area of solar deployment.

The PM-KUSUM scheme was designed to support the solarisation of the agricultural sector through three broad components covering decentralised renewable-energy plants, standalone solar agricultural pumps and solarisation of grid-connected agricultural pumps.

As of 30 September 2026, the PM-KUSUM national portal reported : [22]

[21] https://mnre.gov.in/en/notice/guidelines-for-pm-surya-ghar-muft-bijli-yojana/
[22] https://pmkusum.mnre.gov.in/#/landing

Table 7: PM - KUSUM Statistics

Component	Indicator	Sanctioned MW/ Nos.	Achievement as of 30 Sep.2026	% Of Achievement
Component A	Installed capacity	10,000 MW	2,426 MW	24.3
Component B	Off grid Stand-alone Solar Agriculture Pumps.	13,07,190	11,90,639	91.1
Component C-IPS	Solarisation of grid connected agriculture pumps	55,392	16,528	29.8
Component C-FLS	Solarisation of agriculture feeder	35,36,602	17,17,983	48.6

Component A supports the development of decentralised ground-mounted or stilt-mounted renewable energy power plants, ranging from 500 kW to 2 MW.Component B focuses on the installation of off-grid standalone solar agricultural pumps.Component C - Individual Pump Solarisation (IPS) aims at the solarisation of grid-connected agricultural pumps, while Component C - Feeder-Level Solarisation (FLS) focuses on the solarisation of 35 lakh grid connected agricultural pumps.

The implementation progress of the PM-KUSUM scheme as of 30 September 2026 reflects varying levels of achievement across its components.Component B has demonstrated substantial progress, with 11.91 lakh standalone solar agricultural pumps installed, achieving 91.1% of the sanctioned quantity.In comparison, Component A has achieved 2,425.99 MW of installed capacity against 10,000 MW sanctioned, representing 24.3% progress.Under Component C, Individual Pump Solarisation (IPS) has achieved 29.8%, while Feeder-Level Solarisation (FLS) has reached 48.6% of their respective targets sanctioned.The implementation gap across these components indicates considerable scope for further decentralised solar deployment and highlights the importance of strengthening technical workforce availability, particularly in solar pump installation, electrical integration, commissioning, troubleshooting and long-term operations and maintenance across rural areas.

2.1.6. Key Takeaways

The following key observations emerge from the solar-energy landscape:

1. Solar PV has become the leading driver of global renewable energy expansion, with global annual additions exceeding 600 GW in 2025
2. India has become a major global solar market, commissioning almost 50 GW of solar PV during 2025
3. India's cumulative solar capacity reached 171.05 GW by September 2026, with ground-mounted systems accounting for the majority of installed capacity
4. Distributed applications are gaining importance, particularly rooftop and agricultural solar
5. Solar technology is becoming increasingly sophisticated, with higher-efficiency cell technologies, bifacial modules, trackers and hybrid systems
6. Energy storage and grid integration are becoming increasingly important as the share of variable renewable generation increases
7. Digitalisation is changing solar operations, increasing the relevance of SCADA, analytics, AI, remote monitoring and predictive maintenance
8. Domestic manufacturing capabilities are expanding, creating additional requirements for manufacturing, quality, process engineering and automation skills

9. The future solar workforce will require a combination of technical, digital, analytical and interdisciplinary capabilities

The evolving technology and deployment landscape creates the need for a systematic assessment of current and future skill requirements, which forms the focus of the subsequent chapters of this assessment.

2.2.Solar Energy Value Chain

The global solar photovoltaic industry operates along a tightly integrated, capital-intensive manufacturing and deployment continuum.Spanning upstream raw material extraction through downstream lifecycle management, the sector transforms quartz into utility-scale clean electricity.Each phase requires distinct technical competencies, capital allocation strategies, and risk mitigation frameworks.

Upstream operations establish the foundational material quality of the system.The cycle begins with the carbothermic reduction of high-purity quartz in electric arc furnaces to yield metallurgical-grade silicon.This silicon is subsequently reacted to form volatile trichlorosilane gas, subjected to rigorous fractional distillation, and refined into solar-grade polysilicon.Manufacturers melt this material in quartz crucibles to pull single-crystal cylindrical ingots with precise p-type or n-type doping.These ingots are shaped into square blocks and sliced into paper-thin substrates via high-speed diamond wire saws, producing silicon wafers engineered to exact mechanical and dimensional tolerances.

Midstream manufacturing converts inert silicon wafers into active semiconductor junctions and protective enclosures.Wafer substrates are textured to minimise light reflection, treated with chemical dopants to establish the internal p-n junction, layered with silicon nitride anti-reflective coatings, and printed with silver-aluminum conductive contact lines.In recent years, the market has undergone a structural transition away from legacy passivated emitter and rear cell (PERC) architectures toward higher-efficiency n-type platforms, primarily tunnel oxide passivated contact (Topcon) and silicon heterojunction (HJT) designs.Once tested and sorted by electrical output, cells are soldered into strings, laminated between ultraviolet-resistant encapsulants such as ethylene-vinyl acetate or polyolefin elastomers, and backed by specialised weatherable back sheets or secondary rear glass for dual-sided light absorption.The laminated matrix is then framed into structural anodized aluminum and fitted with an integrated junction box to complete the durable module assembly.

Beyond module manufacturing, the Balance of System encompasses the electrical and structural hardware essential to power integration.Central, string, or micro-inverter architectures convert direct current generated by the arrays into grid-compliant alternating current, using maximum power point tracking to optimise yield under variable atmospheric conditions.Structural support is provided by fixed-tilt ground racking or motorised single-axis tracking systems that shift panel orientation toward the sun across the day.Supporting electrical components-including high-voltage transformers, switchgear, direct current combiner boxes, rapid-shutdown hardware, and grounding networks-ensure grid synchronisation, voltage step-up, and continuous operational safety.

Downstream activities focus on project origination, physical execution, and multi-decade asset operations.Project developers identify suitable parcels, execute environmental and geotechnical assessments, secure interconnection rights, and negotiate long-term power purchase agreements. Engineering, procurement, and construction (EPC) contractors manage heavy civil works, mechanical piling, electrical installation, and rigorous commissioning protocols under strict schedule guarantees. Following energisation, operations and maintenance teams rely on automated supervisory control and data acquisition systems, aerial infrared thermography, and predictive maintenance schedules to sustain availability and manage component degradation over 25 to 30 years.The chain concludes with decommissioning frameworks, where recycling facilities delaminate modules to recover high-value silver, crystalline silicon, copper, glass, and aluminium for circular industrial reuse.

The global photovoltaic supply chain exhibits extreme geographic concentration, particularly across upstream metallurgical and chemical processing segments.China controls between 75% and 95% of global output across polysilicon refining, ingot crystallisation, wafer sawing, and solar cell fabrication[23].

[23] https://iea.blob.core.windows.net/assets/d2ee601d-6b1a-4cd2-a0e8-db02dc64332c/SpecialReportonSolarPVGlobalSupplyChains.pdf

Unlike downstream module packaging which consists of automated mechanical stringing, lamination, and framing the upstream segment from polysilicon to solar cells operates under pure semiconductor manufacturing physics.In response to supply chain vulnerabilities and domestic decarbonization goals, major global economies have instituted trade regimes and industrial policy incentives designed to rebuild domestic clean energy manufacturing bases.

2.2.1. Major stages of the Solar PV Value Chain

The expansion of the solar value chain is resulting in a diversified employment ecosystem[24].

Table 8: Solar PV Value Chain - Key Activities, Outputs, and Skill Requirement

Stage	Major activities	Key outputs	Representative skill requirements
Raw materials	Silicon, aluminum, glass, silver, copper and polymers	Industrial inputs	Materials science, process engineering, quality
Polysilicon	Purification and conversion into solar-grade silicon	High-purity polysilicon	Chemical/process engineering
Ingot manufacturing	Melting and crystallisation of silicon	Silicon ingots	Materials, thermal and process engineering
Wafer manufacturing	Ingot slicing, cleaning and surface preparation	Silicon wafers	Precision manufacturing, automation
Cell manufacturing	Diffusion, passivation and testing	Solar cells	Semiconductor processing, electrical engineering
Module manufacturing	Cell interconnection, lamination, framing and testing	PV modules	Manufacturing, quality, automation
BoS	Inverters, mounting structures, cables, transformers, SCADA, protection	Plant equipment	Electrical, mechanical, civil and instrumentation
Project development	Land, resource assessment, approvals, financing, PPA	Bankable project	Project development, regulatory, finance
EPC	Engineering, procurement, construction commissioning	Operational solar plant	EPC, construction, electrical and project management
O&M	Monitoring, preventive/corrective maintenance, optimisation	Reliable generation	Electrical, data analytics, diagnostics
End-of-life	Decommissioning, reuse, recycling and waste management	Recovered materials	Recycling, environmental management

[24] https://www.iea.org/reports/energy-technology-perspectives-2026/supply-chain-risks-and-industrial-competitiveness

The skill profile is therefore moving from an equipment-oriented workforce towards a multidisciplinary workforce combining engineering, digitalisation, analytics, project management and sustainability capabilities.

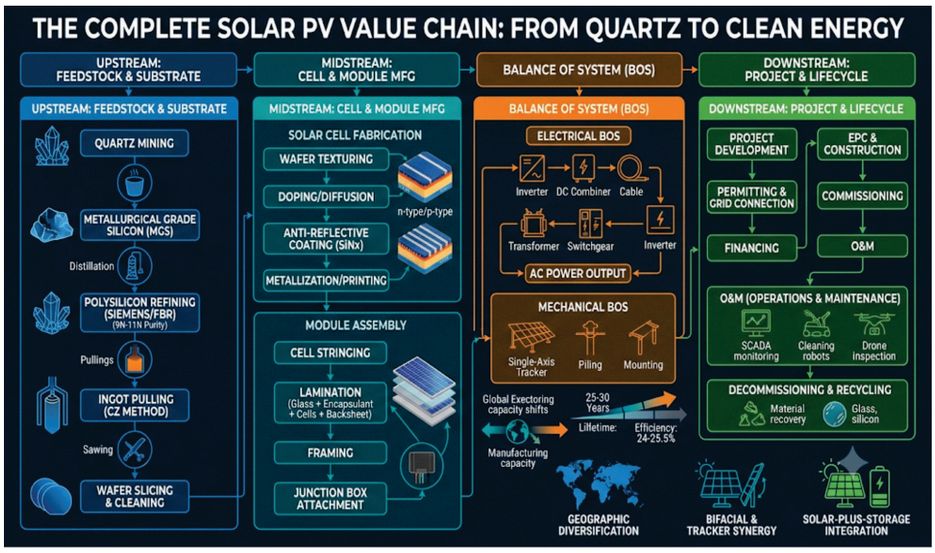


Figure 19: Solar PV Value Chain

2.3. Key Takeaways

The solar energy value chain is expanding from conventional PV manufacturing and project deployment towards an integrated ecosystem involving advanced manufacturing, digitalisation, storage, grid integration and circularity.

1. Global scale is expanding rapidly: Solar PV additions exceeded 600 GW globally in 2025, with cumulative capacity reaching approximately 2,800 GW
2. India is a major solar market: India's cumulative solar capacity reached 171.05 GW as of 30 September 2026
3. Domestic manufacturing is expanding India's ALMM-listed module manufacturing capacity reached approximately 228 GW/year by the end of September 2026[25]
4. Cell manufacturing is emerging as a strategic capability: Around 35 GW of solar cell manufacturing capacity had been enlisted under ALMM List-II
5. Advanced technologies are changing skill requirements: Topcon, HJT, advanced module architecture, automation and digital inspection are increasing demand for specialised technical skills
6. Digitalisation is becoming crosscutting: SCADA, AI, machine vision, drones, predictive maintenance and data analytics are becoming increasingly important across manufacturing and asset operations
7. Storage is becoming integrated with solar: Solar-plus-BESS projects are creating new requirements in battery systems, power electronics, energy management and grid integration
8. End-of-life management will become increasingly relevant: India's growing installed base will create future demand for PV recycling, material recovery and circular-economy capabilities
9. Skill development needs to be value-chain specific: A single generic solar training curriculum will not adequately address the different competency requirements of manufacturing, EPC, O&M, project development, storage and asset management
10. The future workforce will be multidisciplinary: The solar sector increasingly requires professionals combining electrical/mechanical engineering with digital, analytical, project-management, regulatory and sustainability competencies

[25] https://www.pib.gov.in/PressReleasePage.aspx?PRID=2298869&reg=48&lang=1



3 Methodology

3.1.Overall Approach

This assessment combines industry research, analysis of existing data and learning from international practices.The work is organised into five stages:

1. **Stage I - Mapping the value chain:** Mapping the activities involved from resource assessment and project development to manufacturing, construction, installation, commissioning, grid integration, operations, maintenance, and decommissioning.This helps identify the job roles covered by the assessment.
2. **Stage II - Collecting primary data:** Gathering information through structured discussions with industry stakeholders and an industry survey covering employers across the value chain, training institutions, industry associations and government agencies.The focus is on understanding workforce composition, required skills, recruitment challenges and existing training practices.
3. **Stage III - Estimating workforce demand:** Estimating workforce requirements up to 2030 based on expected capacity growth and the number of full-time equivalent workers needed across various stages of value chain.
4. **Stage IV - Assessing skill gaps and the training ecosystem:** Comparing industry skill requirements with existing training programs, qualification frameworks and the capacity of training institutions.This stage also examines the readiness of training infrastructure.
5. **Stage V - Developing recommendations and a roadmap:** Recommending improvements to curricula, certification systems and training institutions, along with a costed plan for developing the workforce required to support the growth of the sector.

3.2.Stakeholder Coverage

Within each category, organisations were selected to represent both established and emerging segments of the solar energy sector, including solar PV manufacturing, utility-scale and rooftop solar project development, Engineering, Procurement and Construction (EPC), operations and maintenance (O&M), and emerging technologies such as advanced solar cell manufacturing, solar-BESS integration, digital asset management, and solar PV recycling.

1. Solar PV Developers & Independent Power Producers (IPPs) - Workforce requirements for project development, solar resource assessment, engineering design, project financing, construction, grid integration, commissioning, and long-term asset management.
2. Solar EPC Contractors & O&M Service Providers - Technical competencies required for utility-scale and rooftop solar installations, electrical and structural engineering, system integration, testing and commissioning, preventive and corrective maintenance, performance monitoring, and occupational safety.
3. Skill Councils & Training Institutions - Existing Qualification Packs (QPs), NSQF-aligned programs, Surya Mitra training initiatives, training infrastructure, practical laboratory facilities, certification mechanisms, and alignment with evolving industry requirements.
4. Academic & Research Institutions - Technical education, specialized research in advanced PV technologies, curriculum development, industry-academia collaboration, internships, and research initiatives.
5. Workforce & Industry Professionals - Practical competency gaps, emerging technical skill requirements, upskilling and reskilling needs, occupational mobility, career progression, workforce readiness, and workplace health and safety across the solar PV value chain.

3.3.Data Collection Methodology

The Solar Energy Sector Skill Gap Assessment adopts a structured, multi-stakeholder data collection approach to assess workforce availability, occupational competencies, recruitment challenges, training infrastructure, and emerging skill requirements across the solar energy value chain in India.The methodology combines structured survey questionnaires and semi-structured stakeholder interviews to capture both quantitative workforce information and qualitative industry insights.The assessment encompasses polysilicon, ingot, wafer, cell and module manufacturing, rooftop and utility-scale solar project development, Engineering, Procurement and Construction (EPC), grid integration, operations and maintenance (O&M), and emerging technologies.

1.Survey Forms

Structured survey questionnaires were developed to collect information from solar project developers, Independent Power Producers (IPPs), solar PV manufacturers, EPC contractors, O&M service providers, academic institutions, training organizations, and other relevant stakeholders.

The surveys focus on the following parameters:

1. Workforce Availability - Existing workforce strength, qualification levels, and availability of skilled workforce across solar manufacturing, project development, EPC, and O&M.
2. Skill Gap Identification - Identification of skill gaps across the solar value chain.
3. Recruitment Challenges - Hiring constraints, experience requirements, workforce mobility, and availability of industry-ready professionals.
4. Training Requirements - Existing training programs, NSQF-aligned certifications, Surya Mitra initiatives, apprenticeships, industry-specific training, and upskilling and reskilling requirements.
5. Emerging Technologies - Skills required for Topcon and HJT cell technologies, automated production lines, solar tracking systems, AI/ML applications, digital twins, and predictive maintenance.
6. Training Infrastructure - Availability of practical training facilities, manufacturing equipment, electrical testing laboratories, solar PV simulators, qualified trainers, advanced research facilities, and occupational safety training infrastructure.
7. Future Workforce Demand - Anticipated workforce requirements associated with domestic manufacturing expansion, rooftop and utility-scale solar deployment, and technological advancements.

2.Interviews

The interviews focused on the following areas:

1. Value Chain-Specific Skill Requirements - Technical competencies across polysilicon, ingot, wafer, cell and module manufacturing, installation, commissioning and O&M.
2. Workforce Competency Gaps - Differences between existing workforce capabilities and industry-specific requirements in semiconductor processing, manufacturing automation, process optimisation, and solar plant performance management.
3. Recruitment and Retention Challenges - Availability of experienced professionals, specialised technical expertise, workforce mobility, employee retention, and recruitment challenges across manufacturing facilities and remote solar project locations.
4. Training Program Effectiveness - Industry relevance of existing academic curricula, Surya Mitra training, Skill Council for Green Jobs (SCGJ) Qualification Packs (QPs), NSQF-aligned certifications, and practical training arrangements.

5. Emerging Skill Requirements - Specialised competencies in advanced PV cell architectures, polysilicon-to-module manufacturing, equipment commissioning, PLC/SCADA, AI/ML-based defect detection, digital monitoring, predictive maintenance.
6. Industry-Academia Collaboration - Opportunities for industry-oriented curriculum development, internships, apprenticeships, faculty development, joint R&D programmes advanced laboratory infrastructure, and specialized Centres of Excellence involving universities, engineering colleges, polytechnics, and solar industry stakeholders.
7. Skill Development Recommendations - Stakeholder perspectives on strengthening training infrastructure, updating occupational qualifications, expanding practical training opportunities, improving institutional capacity, and developing an industry-ready workforce capable of supporting India's expanding solar energy sector

3.Data Consolidation and Analysis

Survey responses and interview findings were systematically consolidated to assess workforce demand, occupational skill shortages, competency gaps and training requirements across the solar energy value chain.

Quantitative data were analysed using descriptive statistics, including workforce distribution, recruitment requirements, reported skill shortages and training participation.Qualitative findings were examined through thematic analysis to identify recurring challenges and emerging competency requirements.

Where applicable, identified occupational requirements were mapped against existing Qualification Packs (QPs), National Occupational Standards (NOS), National Skills Qualification Framework (NSQF) levels and relevant solar industry safety and technical certification frameworks.

The analysis also distinguished between three dimensions of skill gaps:

1. Workforce Availability Gaps: Shortages in the number of qualified workforce available for specific occupations.
2. Competency Gaps: Differences between workforce capabilities and industry required technical skills.
3. Emerging Skill Gaps: Inadequate preparedness for digital technologies and evolving operational requirements.

3.4.Workforce estimation methodology

3.4.1.Unit of Measurement

1. Direct Employment - Jobs directly associated with polysilicon, ingot, wafer, cell and module manufacturing, solar project development, engineering design, installation, commissioning, grid integration, and solar plant operations and maintenance (O&M).
2. Indirect Employment - Jobs generated across the broader solar value chain and supporting industries, including raw material processing, glass and aluminium manufacturing, electrical equipment, mounting structures, cables, inverters, transportation, logistics, civil construction, and related services.
3. Induced Employment - Jobs supported by the expenditure of wages earned by workers engaged in direct and indirect employment.

3.4.2. Business Phases

Workforce requirements are estimated separately for solar project deployment and manufacturing.

Table 9: Business Phases for Estimation of solar

Deployment	Manufacturing
Business development	Material procurement
Design and pre-construction	Engineering and design
Construction and commissioning	Production
Operations and maintenance (O&M)	Business development/Corporate functions

Table 10: Business Phases for Estimation for Decentralized Renewable Energy Application

Solar Street lights	Solar Water Pumps
Solar Streetlight Manufacturing	Pump manufacturing
Controller Manufacturing	Controller manufacturing
System Integration	System Integration

3.4.3. Capacity Trajectory

The solar energy workforce projections are based on India's renewable energy expansion objectives, including the national target of achieving 500 GW of non-fossil fuel-based installed electricity capacity by 2030.The assessment estimates workforce requirements across ground-mounted solar, rooftop solar, floating solar and solar module manufacturing using technology-specific employment coefficients.

The study estimates how much new capacity would need to be installed each year to reach this target. This is important because the workforce required for construction and installation depends on the amount of new capacity added each year.

Workforce Estimation Methodology

The study presents workforce requirements in three ways:

1. Cumulative job-years: The total employment effort required to manufacture and install additional solar capacity over the study period.
2. Annual workforce demand: The number of workers required each year for manufacturing, installation and commissioning, and operations and maintenance (O&M).
3. Sustained employment: The workforce needs to operate and maintain solar farms as installed capacity increases.These jobs continue even after construction is completed.

These estimates are calculated using employment coefficients and projected capacity additions. Estimating annual and sustained employment also requires assumptions about the installation schedule, the share of equipment manufactured in India, the duration of project-related work, and the workforce needed for O&M.

1.Solar Deployment Scenarios

The study considers workforce requirements across three major solar deployment segments: ground-mounted solar, rooftop solar and floating solar.These scenarios account for differences in project scale, installation activities, employment intensity and operational requirements.Ground-mounted solar workforce demand is primarily driven by utility-scale capacity additions, while rooftop solar generates comparatively higher employment per MW due to decentralised installations and associated service requirements.Floating solar introduces additional workforce requirements for specialised installation and maintenance activities.Employment projections are estimated using technology-specific capacity additions and employment coefficients, with cumulative job-years assessed separately from annual workforce demand.

2.Solar Manufacturing Scenarios

The study considers solar module manufacturing as a separate workforce demand segment, accounting for manufacturing capacity expansion, production activities, automation and specialised technical requirements.Workforce projections are influenced by the scale of domestic manufacturing, production-line utilisation and the adoption of advanced manufacturing technologies.As manufacturing employment depends on actual production activity rather than installed generation capacity alone, employment requirements are assessed separately from solar deployment to avoid double counting and identify specific skill requirements across production, quality control, equipment maintenance and process engineering.

3.4.4. Assumptions and Limitations

1. Workforce and capacity: It assumes that workforce requirements increase in proportion to capacity.It does not account for possible reductions in workforce needs due to larger projects, improved technology or higher productivity.
2. Accuracy of reported data: Employment figures provided by companies are used for the estimates, subject to further checks and validation.
3. Jobs versus workers: The number of jobs created is not the same as the number of people employed.One person may work on several short-term projects over time, meaning the total number of jobs created can be higher than the increase in the overall workforce.
4. Realistic capacity growth: Projections are based on expected capacity additions rather than total estimated solar resource potential.Not all potential capacity can be developed because of constraints such as land availability, transmission access and project costs.

3.5. Skill Gap Assessment Framework

Skill gaps in the solar industry can occur at three different levels.Each requires a different solution.This assessment separates these gaps to ensure that recommendations address the actual problem.

1. Level 1 - Shortage of workers.There are not enough people available for a particular job, regardless of their skill level.This can be addressed by increasing recruitment and training more people.
2. Level 2 - Shortage of skills.Enough workers may be available, but they may lack the technical knowledge, practical experience or safety skills required by the industry.This can be addressed by improving training programs, providing more hands-on experience and introducing relevant certifications.
3. Level 3 - Skills needed for recent technologies and roles.Existing training programs may not cover the skills required for recent technologies and emerging areas such as digital operations and maintenance, predictive maintenance, condition monitoring, advanced solar PV technologies, hybrid systems and solar PV manufacturing.This requires new or updated training content and qualifications.

3.5.1. Assessment Parameters

Each job role is assessed using the following parameters to identify where the gaps exist and what action is needed.

Parameter*	What is assessed
Recruitment difficulty	How long employers take to fill vacancies and how difficult it is to find suitable candidates
Competency gap	Whether new recruits have the skills needed to perform their jobs
Time to competence	How long employees take to become capable of working independently
Training availability	Whether suitable training programs and qualifications are available
Certification requirements	What safety and technical certifications are needed and whether they are available in India
Geographic availability	Whether qualified workers are available near project locations

**Parameters are assessed through employer responses in the industry survey and stakeholder consultations, supplemented by mapping against published qualification frameworks*

3.5.2. Mapping Qualifications

The skills required for each job role are compared with the National Skills Qualifications Framework (NSQF) and existing Qualification Packs developed by the Skill Council for Green Jobs (SCGJ) and the National Institute of Solar Energy (NISE).

This helps classify job roles into three categories:

1. Roles for which suitable and up-to-date qualifications already exist.
2. Roles for which qualifications exist but need to be updated to reflect current technologies and industry practices.
3. Roles for which no suitable qualification is currently available.

The mapping also identifies qualifications that are outdated, where occupational standards have not been updated to keep pace with changes in cell technology, operating practices and digital systems.

3.5.3. Technology-Specific and Transferable Skills

Industry consultations and sectoral assessments indicate that solar PV technologies require a combination of standardised technical competencies and manufacturer-specific operational knowledge.While fundamental principles of solar PV system design, installation, commissioning and maintenance are broadly transferable across technologies, specialized competencies associated with inverter configurations, monitoring platforms, automated manufacturing equipment and diagnostic systems often depend on the equipment manufacturer and technology deployed.

The increasing adoption of advanced solar cell and module technologies, automated production lines, smart inverters and digital asset management platforms has further expanded the need for technology-specific training.Workforce with experience in one equipment platform may require additional training to operate, troubleshoot or maintain systems supplied by another manufacturer.This is particularly relevant for solar module manufacturing facilities, EPC contractors and third-party O&M service providers managing equipment from multiple suppliers.

The assessment therefore distinguishes between two categories of competencies:

1. Transferable skills: Competencies applicable across different solar PV technologies and equipment platforms, including electrical safety, solar PV fundamentals, system design, installation, commissioning, quality inspection, performance assessment, basic troubleshooting, SCADA data interpretation and preventive maintenance.These skills can be developed through standardised vocational training, engineering education and industry-recognised certification programs.
2. Technology-specific skills: Competencies associated with solar module technologies, inverter architecture, automated manufacturing equipment, monitoring platforms and proprietary diagnostic software.These include equipment parameter configuration, advanced fault diagnostics, machine programming, process optimisation and manufacturer-specific maintenance procedures, which require specialised training through OEMs or authorised technical partners.

Access to proprietary software, equipment interfaces, operational datasets and advanced diagnostic tools may be restricted by manufacturers, limiting the ability of independent training institutions to provide comprehensive practical instruction across different technology platforms.Consequently, training institutes should prioritise foundational electrical and mechanical competencies, solar PV system engineering, automation principles, sensor technologies and data analytics, while industry partners should provide supplementary equipment-specific training and practical exposure.

This distinction enables the assessment to identify skill gaps that can be addressed through standardised training curricula and NSQF-aligned qualifications, while recognising the need for OEM-led technical specialisation to ensure workforce readiness across evolving solar technologies.

3.6. Readiness of Training Institutes

Training ecosystem readiness is assessed across five dimensions, each selected to identify constraints that would limit the sector's capacity to meet projected workforce requirements.

1. Curriculum alignment: Coverage of current solar industry technologies, practices and emerging competency requirements, assessed against the skill gaps identified in Chapter 4.This includes advanced solar PV technologies such as Topcon, HJT and bifacial modules; automated solar module manufacturing, utility-scale and rooftop solar system design, floating solar, digital operations and maintenance, SCADA-based performance monitoring, predictive maintenance, and solar asset management.
2. Trainer capacity: Availability of qualified trainers with expertise in solar PV design, manufacturing, installation, commissioning, testing and O&M.The assessment considers trainers' direct industry exposure, familiarity with evolving solar technologies, practical experience with industry-standard software and equipment,
3. Practical training infrastructure: Availability of solar PV demonstration systems, rooftop and ground-mounted installation facilities, module testing laboratories, inverter and electrical laboratories, solar pump training systems, and SCADA and performance monitoring platforms.For manufacturing related training, the assessment considers access to stringing, lamination, electroluminescence (EL) testing, flash testing, quality inspection and automated production equipment.Additional consideration is given to electrical safety, working-at-height facilities.

4. Certification and accreditation status: Recognition and alignment with the National Skills Qualifications Framework (NSQF), National Council for Vocational Education and Training (NCVET), Ministry of Skill Development and Entrepreneurship (MSDE) frameworks, and relevant Qualification Packs developed through the Skill Council for Green Jobs (SCGJ).The assessment also considers alignment with applicable IEC standards, industry-recognized technical certifications, manufacturer-specific training programs and competency-based practical assessment requirements.
5. Capacity and geographic positioning: Annual training capacity, enrolment and completion rates, geographic accessibility and proximity to major solar manufacturing clusters, utility-scale solar parks, rooftop solar markets and decentralised renewable energy deployment areas.The assessment also examines industry partnerships, internship and apprenticeship opportunities, placement rates, employer feedback and the extent to which training outcomes align with regional and national solar workforce requirements.

3.6.1. Institutions Covered

The assessment covers the following categories of training providers

1. The National Institute of Solar Energy (NISE) and its network of affiliated training partners.
2. Solar PV Manufacturers (OEMs) provide specialised technical and equipment-specific training.
3. Institute of National Importance like IITs and NITs.

3.6.2. Basis of Assessment

The assessment uses input from training institutions, published program details, qualification pack specifications, training records and site visits wherever possible.

Employers are consulted separately to understand how professional training programs prepare candidates for industry requirements.These discussions cover employers experience of hiring trained candidates, the additional training new recruits need before they can work independently, and the extent to which companies depend on in-house training rather than external training providers.

3.6.3. Geographic Positioning of Training Provision

The assessment examines the geographic distribution of solar energy training centres in relation to major solar parks, manufacturing clusters and areas with significant rooftop and decentralised solar deployment.Workforce mobility and the availability of locally trained workforce are important considerations, particularly for utility-scale solar projects located in remote areas.Training and recruiting individuals from communities near solar installations can improve workforce availability, reduce relocation challenges and support long-term employment retention.Accordingly, the assessment considers the proximity of training institutions to solar project locations and manufacturing facilities, emphasising the importance of regionally accessible, industry-linked training programs that align with local employment opportunities and emerging skill requirements.

3.7. Selection of States

States are selected based on their installed solar PV capacity, upcoming utility-scale and rooftop solar projects, solar module and cell manufacturing activity, decentralised solar deployment, and the availability of existing training infrastructure.The assessment considers differences in solar energy development across states to identify region-specific workforce requirements, skill gaps and training priorities.

This selection provides coverage across large solar parks, rooftop markets, off-grid applications and hybrid installations.

Table 11: Priority States for Solar Energy Sector Skill Gap Assessment by Technology Segment

Solar component	Priority states for assessment	Workforce assessment focus
Ground-mounted solar	Gujarat,Karnataka,Maharastra, Rajasthan,Tamilnadu	EPC, installation, commissioning, electrical works and O&M
Rooftop solar	Gujarat,kerala,Maharastra, Rajasthan,Haryana,Tamilnadu	PV installers, electricians, designers, sales and service technicians
Hybrid solar component	AndhraPradesh, Gujarat, Karnataka, Rajasthan	Hybrid system engineering, electrical integration, controls and O&M
Off-grid solar / PM-KUSUM Component B	Chattisgarh,UttarPradesh, Maharastra,Rajasthan,Haryana	Solar pump installation, field technicians, electrical maintenance and rural service networks
Solar manufacturing	Gujarat, Tamil Nadu, Maharashtra, Andhra Pradesh, Rajasthan and Odisha	Production, process engineering, quality assurance and equipment maintenance
Floating solar	Telangana, Karnataka, Odisha.[25]	Floating structures, electrical safety, anchoring, mooring systems inspection and specialized O&M

3.7.1. Rationale

Solar energy employment is distributed across utility-scale projects, rooftop installations, decentralised applications and manufacturing facilities.Consequently, the availability of skilled workers at the national level does not necessarily indicate their availability in locations where solar projects are being developed or manufacturing activities are concentrated.

Utility-scale solar projects are frequently located away from major urban centres, creating challenges in recruiting and retaining technical workforce for construction and long-term O&M activities.In contrast, rooftop solar generates geographically dispersed employment opportunities across urban, semi-urban and rural markets, requiring locally available technicians and service providers.Solar manufacturing creates concentrated demand for production operators, process engineers, quality professionals and maintenance workforce near industrial clusters.

The state-level assessment therefore distinguishes between workforce demand arising from new solar capacity additions, sustained O&M requirements, rooftop and decentralised solar deployment, and manufacturing activities.This approach helps identify geographic mismatches between workforce demand and training availability and supports the development of region-specific skill development programs aligned with local industry requirements.

[25] https://nise.res.in/upload/NISE_floating%20potential_report_2026.pdf



4.Workforce and Skill Gap Analysis

4.1.Key Survey Findings

During the survey visits conducted across all major industry stakeholders which included multiple segments of the solar industry value chain, consultations were held with solar PV manufacturers (ingots & wafers, solar cells and solar modules), Engineering, Procurement & Construction (EPC) companies, Independent Power Producers (IPPs), asset management & Operations and Maintenance (O&M) companies as well as Academic and Training institutes.

The discussions with key senior workforce in various organisations provided insights into the existing workforce profile, recruitment practices, training arrangements, emerging skill requirements, workforce retention policies and challenges associated with developing an industry-ready workforce.The findings indicate that the rapid expansion of domestic solar manufacturing installed capacity as well as the increasing solar energy deployment for power generation, is increasing the need for technically competent workforce across different occupational levels.

The following table shows the estimated current workforce in the solar manufacturing and the solar power generation sectors:

Table 12: Existing Workforce as per current operation and install capacity of solar value chain

Segments	Installed Capacity (Name Plate)	Current Workforce			
	September 2026	Blue Collar	White Collar	Blue Collar	White Collar
Manufacturing	GW	HR/GW	HR/GW	Total HR	Total HR
Module	228.54	280 - 390	70 - 110	29,000* - 40,000	7,500* - 11,500
Cell	35	340 - 480	110 - 170	12,000 - 17,000	4,000 - 6,000
Ingot and wafer	2	210 - 250	130 - 150	420 - 500	260 - 300
Polysilicon**	0	-	-	-	-
Total Human Resource				41,420 - 57,500	11,760 - 17,800
Segment	**Installed Capacity[27]**	**Current Workforce**			
	September 2026	**Blue Collar**	**White Collar**	**Blue Collar**	**White Collar**
Power Generation	GW	HR/GW	HR/GW	Total HR	Total HR
Ground-Mounted solar and Hybrid (Solar Component)	131.01	1,100 - 1,650	210 - 330	37,000***- 55,000	7,000*** - 11,000
Decentralised - (Off-grid & KU-SUM-B)	6.63	1,500 - 2,000	250 -300	2,500 - 3,500	400 - 500
RTS (C&I and Residential)	33.41	2,200 - 2,800	200 -250	22,000 - 28,000	2,000 - 2,500
Total Human Resource	171.05			61,500- 86,500	9,400 - 14,000

[27] https://mnre.gov.in/en/physical-progress/

Blue-Collar Workforce: *The blue-collar workforce comprises workforce engaged primarily on the shopfloor or at site and involved in hands-on technical operations, machinery maintenance, fabrication, and frontline site construction activities. In high-technology and industrial environments such as advanced manufacturing and project sites.This workforce typically holds vocational certificates (e.g., ITI trade certifications), technical apprenticeships, or polytechnic engineering diplomas*

White-Collar Workforce: *The white-collar workforce comprises professional, managerial, administrative, and engineering workforce responsible for strategic planning, process engineering, design optimization, quality control, data telematics, and organizational governance.These roles typically require formal academic qualifications, including undergraduate degrees (B.E./B.Tech), postgraduate engineering credentials (M.Tech/Ph.D.), or specialized management certifications*

PM KUSUM Scheme: *This scheme is for de-dieselisation of farm sector by providing subsidies for installation of new standalone solar pumps, solarization of existing pumps and grid-connected solar power plants up to 2 MW.*

Ground mounted figures also include PM KUSUM component A and C.

**For module manufacturing 45% of name plate capacity is considered as operational capacity to project the workforce deployment*

***Polysilicon manufacturing is yet to start in India*

**** For power generation, the estimated current workforce includes EPC and O&M and has been calculated considering only annual installation in the last financial year (FY-26)*

All total workforce figures are rounded to the nearest 500

Key findings from the survey are summarised below:

- Different skill requirements across the value chain: Ingot and wafer production and solar cell manufacturing require specialised crystal growth process and material science knowledge, equipment-handling skills, a stronger understanding of clean room protocols, automation and thermal & chemical process control.Module assembly requires knowledge in advanced robotics to operate and maintain automated tabbing & stringing, lay-up robots and laminators as well as skill in image analysis for inspection and quality control.
- Growing importance of digital skills: Artificial intelligence (AI), machine learning (ML), Automated Optical Inspection (AOI), robotics and data-based performance monitoring are becoming increasingly relevant to manufacturing quality, production efficiency and solar power generation plant operations.
- Continued dependence on entry-level recruitment: ITI, diploma and engineering graduates are recruited for shop-floor operations, maintenance, quality, engineering and supervisory positions.Due to fairly high attrition rates, frequent recruitment of fresh employees is necessary.These fresh recruits require structured induction and practical training for a few months, before they can perform independently.
- Variation in training arrangements: Training duration ranges from short induction programmes of 2-3 days to structured programmes lasting 7-12 days.Some organisations also reported extended classroom and onsite training lasting 3-10 months, depending on the job role and technical complexity.
- Limited access to specialised training infrastructure: Industry consultations highlighted the need for dedicated facilities for solar manufacturing, equipment operation, automation, robotics, electroluminescence (EL) image analysis, advanced inspection and troubleshooting in ITIs and other academic institutes/ skill development centres.
- Workforce retention challenges: Attrition, relocation, contractual employment and the availability of workers near manufacturing locations affect workforce continuity.Reported attrition levels vary by workforce category and operational context, with survey responses indicating approximately 15- 30%.
- Need for stronger industry-academia collaboration: Survey participants highlighted the need for a higher level of industry-academia collaboration to improve practical exposure, development of curricula, establish specialised training facilities and to ensure research and doctoral programs are aligned with the needs of the industry.

The findings demonstrate that workforce development needs to progress alongside capacity expansion.A combination of practical training, specialised technical education, industry-aligned curricula, certification and structured career progression will be important for building a skilled and sustainable workforce across the solar industry.

4.2.Current Workforce and Skills

The workforce across the solar industry comprises ITI-qualified workforce, diploma holders, engineering graduates, experienced technicians, supervisors, managers and specialised professionals.The distribution of these categories varies according to the manufacturing process, automation level, facility size and operational requirements.

Survey responses indicate that ITI and diploma holders form a substantial part of the technical and shop-floor workforce, while engineers and experienced professionals are required for process engineering, equipment maintenance, automation, quality assurance, project execution, performance monitoring and management.

Survey responses indicated a workforce composition of approximately 78% blue-collar workforce and 22% white collar.The survey also highlighted differences in recruitment and training requirements across the value chain.Module manufacturing requires workforce who can operate and monitor automated production lines, while ingot, wafer and cell manufacturing demand more specialised process knowledge and an understanding of equipment, materials and production parameters.

4.2.1.Ingot and Wafer Manufacturing

In the solar PV value chain, Ingot and Wafer Manufacturing (ingot pulling using Czochralski/CZ crystal growth furnaces, followed by squaring, bricking, and multi-wire diamond saw slicing) is the most capital-intensive, high-temperature, and energy-dense phase.

Operating a CZ crystal pulling hall requires continuous thermal management (furnaces running 24/7 at 1,420°C) and multi-day batch cycles, while the diamond-wire wafering segment requires precision mechanical alignment, coolant recycling, and ultra-thin wafer handling.

Ingot and wafer manufacturing represents an upstream segment of the solar PV value chain and requires elevated level of knowledge in material science to understand and control lattice defects and impurities in crystal growth, skills in managing thermal gradients, process monitoring and quality control.The skills required in this segment differ from those needed for module assembly because of the complexity of manufacturing processes and the need to maintain strict production parameters.

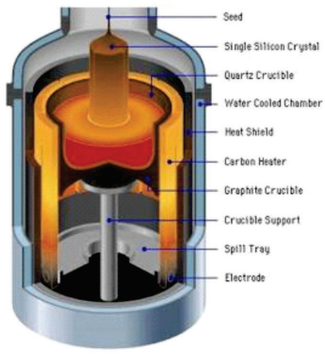


Figure 20: Czochralski (CZ) Crystal Growth Process for Monocrystalline Silicon ingots

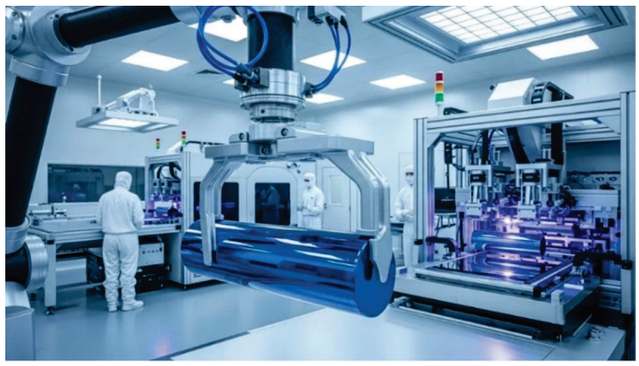


Figure 21 : Solar ingot slicing into wafers

The principal workforce requirements identified for this segment include:

- Operation and monitoring of specialised manufacturing equipment.
- Understanding of material and chemical properties and process parameters.
- Equipment, maintenance, fault diagnosis and troubleshooting.
- Automation, robotics and control-system operation.
- Quality inspection and process optimisation.
- Understanding production software and digitally controlled equipment.

Recruitment practices include hiring ITI and diploma holders for technical positions and engineering graduates for process, maintenance and supervisory roles.Mechanical, electrical and metallurgical backgrounds were identified as relevant to manufacturing operations.Experience in automation and related manufacturing industries can also provide a useful foundation for adapting to solar manufacturing equipment.

Specialised training is essential for developing skilled workforce in ingot and wafer manufacturing. Training programmes also include overseas exposure to advanced manufacturing equipment, production processes, and operational practices.Workforce with ITI-level qualifications and 2-3 years of relevant experience are provided with specialised training in ingot manufacturing.In addition, the engagement of experienced international professionals for a defined period are facilitating knowledge transfer, strengthening technical capabilities, and support the development of a skilled local workforce.

Dependence on imported machinery, software and technical support was identified as a concern. Limited domestic expertise in specialised equipment operation, maintenance and upgrades can affect the development of indigenous manufacturing capabilities.Collaboration between equipment manufacturers, technical institutions and industry can help strengthen local skills and support the development of domestic equipment and software solutions.

Table 13: Workforce Deployment per 1 GW Ingot & Wafer Capacity

Workforce Category	% Share	Head-count/ GW (Range)	Head-count/ GW	Key Functional Roles & Responsibilities	Core Skills & Qualifications
Blue-Collar	60%-65%	210-250	230	• CZ Puller & Crystal Growth Operators: Roles: Polysilicon & dopant charge preparation, quartz crucible positioning, seed crystal alignment, neck/shoulder/body pull monitoring, and safe ingot hot discharge. • Wafering, Squaring & Diamond Wire Saw Technicians: Roles: Ingot cropper/squaring machine operation, mounting ingots on beam/resin, diamond-wire guide alignment, slicing machine oversight, and automated demounting/cleaning. • Mechanical, Thermal & Electrical Maintenance Technicians: Roles: Graphite heater replacement, vacuum pump overhaul, argon gas line maintenance, chiller plant upkeep, high-purity water handling, and wire saw guide repairs. • Inline Metrology, Cleaning & Quality Technicians: Roles: Ultrasonic batch cleaning, wafer thickness & TTV (Total Thickness Variation) inspection, resistivity/lifetime probe testing, micro-crack verification, and cassette loading. • Polysilicon Stores, Chemical Handling & Material Logistics: Roles: Raw chunk/granule polysilicon sorting, crucible storage, coolant/slurry recovery, wire recycling, and finished wafer packaging/clean packaging handling.	ITI/diploma in mechanical, electrical, electronics, instrumentation or related disciplines; crystal growth and wafering equipment operation; thermal and vacuum systems; precision measurement; automation; material handling; and industrial safety.

Workforce Category	% Share	Head-count/ GW (Range)	Head-count/ GW	Key Functional Roles & Responsibilities	Core Skills & Qualifications
White-Collar	35%-40%	130-150	140	• CZ Process Engineering & Crystallization R&D: Role: Melt temperature control, pull-rate optimization, oxygen/carbon defect minimization, dopant concentration distribution, and thermal shield geometry design. • Wafering & Diamond-Wire Process Engineering: Role: Wire consumption optimization, line speed tuning, kerf loss reduction (achieving sub-110 µm wafer thicknesses), and surface yield improvement. • Equipment Maintenance, Vacuum & Automation Management: Role: Preventive maintenance of high-power transformers, heavy vacuum pump stations, argon recovery systems, and automated guided vehicles (AGVs). • Quality Control (QC), Metrology & Defect Analysis: Role: Crystallographic orientation checks, carbon/oxygen FTIR analysis, resistivity profiling, and raw polysilicon/crucible quality control.	B.Tech/B.E./M.Tech in materials science, metallurgy, mechanical, electrical, chemical or related engineering disciplines; crystal growth and thermal process control; semiconductor materials; diamond-wire slicing; metrology; PLC/SCADA; automation; reliability engineering; and EHS management.

4.2.2. Solar Cell Manufacturing

In the Indian solar PV industry, Solar PV Cell Manufacturing (converting silicon wafers into crystalline silicon PV cells via TOPCon, Mono PERC, or HJT technologies) is significantly more complex, capital-intensive, and cleanroom-driven than module assembly.

While module production is mechanical assembly, cell manufacturing involves semiconductor-grade processes-including wet chemical etching, high-temperature diffusion, plasma-enhanced chemical vapor deposition (PECVD), anti-reflective coating, metallic screen printing, and sintering.Consequently, cell lines demand higher technical specialization, strict quality control, and round-the-clock process engineering. The process flow includes chemicals and gases like $POCl_3$, BCl_3/BBr_3, silane, ammonia, N_2O, TMA (for ALD AlOx), NF_3 and $HF/HNO_3/KOH$.

Solar cell manufacturing capacity in India is expanding, with manufacturers planning investments in new facilities and capacity additions using technologies such as TOPCon and M-PERC.Planned developments include phased capacity expansions and the establishment of new manufacturing facilities, with several projects targeting commissioning between 2027 and March 2029.These developments reflect the sector's focus on scaling domestic solar cell production, adopting advanced technologies, and strengthening the domestic solar manufacturing ecosystem.

Survey findings suggest that cell manufacturing generally requires more specialised skills than module assembly.Workforce must understand process variations, identify defects and maintain consistency in production quality.Consequently, experienced technicians and engineers are required alongside newly recruited ITI, diploma and engineering graduates.

Solar cell manufacturing operations require a combination of skilled and experienced workforce and newly recruited workers.An indicative workforce requirement of 450 to 650 workforce per GW has been identified for cell operations.Workforce planning may include experienced professionals to support technical operations and knowledge transfer and relevant statutory and regulatory compliances and approvals, alongside fresh recruits who can be trained in manufacturing processes.Permanent employees are also essential for ensuring operational continuity, process control, and effective workforce development.Actual workforce requirements may vary depending on plant capacity, automation levels, technology, and operational structure.

Training arrangements include structured induction, supervised equipment operation and knowledge transfer from experienced workforce.In some cases, specialised overseas workforce are engaged for a defined period to train local employees.This approach can support the transfer of process knowledge, although long-term capability development also requires local trainers, standard operating procedures and institutionalised training programmes.

The survey highlighted the need to establish specialised training facilities for cell manufacturing. Such facilities should provide practical exposure to production equipment, process monitoring, inspection systems and troubleshooting.Training should also cover the operation of digital systems and the interpretation of production data to prepare workers for increasingly automated manufacturing environments.



Figure 22: Solar cell manufacturing line

Table 14: Summary of workforce required in cell manufacturing line

Workforce Category	% Share	Head-count/ GW (Range)	Head-count/ GW	Key Functional Roles & Responsibilities	Core Skills & Qualifications
Blue-Collar	72%-80%	340-480	410	• **Cleanroom & Line Production Operators:** *Roles:* Wafer loading/unloading, wet-texturing chemistry feed monitoring, PECVD line operation, screen-printing machine oversight, and sorting/packing. • **Maintenance, Utility & Mechatronics Technicians:** *Roles:* Mechanical/electrical maintenance, PLC/robotics troubleshooting, high-purity water (DI water) plant handling, chemical delivery systems (CDS), and exhaust/HVAC scrubbers. • **Inline Quality & Analytical Technicians:** *Roles:* Offline sheet resistance measurement, optical microscopy, IV testing calibration, micro-crack/EL inspection, and lifetime measurement. • **Stores, Chemical Handling & Warehouse Crew:** *Roles:* Hazardous chemical storage & transfer, raw wafer inventory handling, finished cell packing, and hazardous waste treatment support. .	Diploma/ITI in Chemical, Electrical, Electronics or Instrumentation; cleanroom protocols; hazardous chemical and pyrophoric gas safety (SiH_4, PH_3, HF); screen-printer alignment; automated carrier/cassette handling.

Workforce Category	% Share	Head-count/ GW (Range)	Head-count/ GW	Key Functional Roles & Responsibilities	Core Skills & Qualifications
White-Collar	20%-28%	110-170	140	• **Cell Process Engineering & R&D:** *Assistant Managers / Managers / Lead Process Engineers:* Optimizing diffusion profiles, passivation layers, silver paste consumption, finger linewidth, and cell efficiency gains. • **Production Operations & Shift Management:** *Shift Leads & Operations Managers:* Managing 3-shift output, line yield (target >97%), uptime, and shift-to-shift handovers. • **Equipment & Automation Engineering:** *Maintenance Managers / Automation Leads:* Directing preventive/breakdown maintenance on complex vacuum chambers, PECVD furnaces, lasers, and automated guided vehicles (AGVs). • **Quality Assurance (QA), Metrology & Reliability:** *QA Managers / Lab Heads:* Chemical concentration analysis, reliability testing (LID/LeTID, thermal cycling), incoming wafer quality, and supplier auditing. • **EHS, Utilities, Chemical Safety & Plant Admin:** *EHS Managers (specialized in silane/HF gas safety), DI Water/ ETP Leads, Supply Chain, Finance, HR, and Site Head.*	B.Tech/B.E./M.Tech/ Ph.D.in Semiconductor Physics, Chemical Engineering, ECE or Metallurgy; thin-film vacuum physics; chemical vapor deposition; optical metrology; carrier-lifetime analysis; cleanroom automation; PLC/SCADA integration; vendor training and production-line adaptation.

4.2.3. Solar Module Manufacturing

Module assembly is a major employment segment within solar PV manufacturing.The workforce includes production-line operators, stringer operators, printing-machine operators, quality inspectors, maintenance technicians, engineers, supervisors and workforce responsible for material handling, stores and production planning.

Solar module manufacturing in India is witnessing significant growth in existing production capacity and planned expansions.Manufacturing capacities vary across facilities, with companies planning to scale up production by 2030 to meet increasing domestic and international demand.Expansion strategies include increasing existing production capacity, establishing new manufacturing facilities, and adopting advanced technologies such as TOPCon and Heterojunction (HJT).These developments highlight the sector's focus on strengthening domestic manufacturing capabilities, improving technological competitiveness, and supporting the growing deployment of solar energy.

The module manufacturing workforce requires practical skills in:

- Automated tabbing, stringing, laminating and module assembly.
- Equipment operation and routine maintenance.
- Electroluminescence (EL) testing and image interpretation.
- Automated optical inspection and defect identification.
- Quality control, testing and traceability.
- Production-line troubleshooting and process monitoring.
- Workplace safety and material handling.
- Production planning and coordination.

Automation in solar module manufacturing has increased the need for equipment-specific technical training and operational skills.Workforce requirements vary depending on production-line design, equipment configuration, plant capacity, and the level of automation.Workforces need to be trained in the operation, monitoring, maintenance, and troubleshooting of automated equipment, including stringers and other critical production machinery.Indicatively, an automated module manufacturing facility may require 80 to 100 workforce per shift per GW of capacity, although actual requirements depend on the manufacturing setup and workforce deployment strategy.

Training practices differ across facilities.Reported arrangements include 7 days of structured training, 12-day programmes comprising 5 days of behavioural training and 7 days of technical training, and shorter induction programmes of 2-3 days.Some facilities use experienced employees to deliver internal training, while others provide practical exposure through dedicated training centres or supervised shop-floor assignments.

Survey participants highlighted the need for specialised training in EL image analysis, automated inspection, machine operation, tool-room activities and advanced manufacturing systems.As automation increases, the role of the workforce is expected to shift from manual operation towards equipment monitoring, troubleshooting, quality analysis and production optimisation.

Contractual employment plays a significant role in some solar module manufacturing operations, with workforce structures comprising both contractual and permanent employees.Manufacturing facilities also employ a substantial number of workers recruited from outside the local state to meet operational requirements.These workforce arrangements create challenges related to worker availability, retention, accommodation, and production continuity.Effective workforce planning, suitable worker facilities, and structured training programmes are important for maintaining operational stability and ensuring consistent production.

The survey also highlighted the importance of training newly recruited employees before assigning them to production lines.When trained workforce leave, replacement workers need time to develop necessary operating skills.A structured system of competency assessment, cross-training and standardised operating procedures can reduce disruption caused by employee turnover.



Figure 23: Fully automated module assembly line

Table 15: Summary of work force required in module assembly line

Workforce Category	% Share	Head-count/ GW (Range)	Head-count/ GW	Key Functional Roles & Responsibilities	Core Skills & Qualifications
Blue-Collar	70% - 85%	280 - 390	335	• **Operations:** Stringer operators, laminator operators, framing/ boxing crews. • **Maintenance & Utility:** Mechanical fitters, electrical technicians, vacuum/compressor mechanics.	• ITI / Technical Trade Certificate • 3-Year Polytechnic Diploma • Machine SOP adherence • Basic equipment troubleshooting • Cleanroom & HSE compliance

Workforce Category	% Share	Head-count/ GW (Range)	Head-count/ GW	Key Functional Roles & Responsibilities	Core Skills & Qualifications
White-Collar	15% - 30%	70 - 100	85	• **Automation & Systems:** Robotics leads, PLC programmers, SCADA and telemetry engineers. • **Quality & Yield:** EL defect analysts, inline metrology leads, reliability/R&D engineers. • **Management & Support:** Shift supervisors, plant managers.	• B.Tech / B.E./ M.Tech / Ph.D. • Semiconductor physics & metallurgy • Advanced PLC/ Robotics programming • Statistical process control & yield optimization • Plant operations management

Table 16: Summary of Comparative Skill Ratios across the Solar PV Supply Chain

Manufacturing Stage	Typical Headcount / GW	Blue-Collar %	White-Collar %	Core Operational Focus
Module Assembly	350 - 500	80%	20%	Mechanical lamination, stringing, assembly & framing
Cell Manufacturing	450 - 650	75%	25%	Cleanroom chemistry, PECVD, metallization & diffusion
Ingot & Wafering (CZ)	300 - 450	65%	35%	High-temp thermal pullers, crystal growth & ultra-thin slicing

4.2.4. Solar Power Generation (IPPs / EPCs / Asset Management)

In the Solar PV Power Generation Sector (utility-scale ground-mounted projects, 100 MW to 1 GW+ solar parks), workforce requirements are evaluated across two distinct operational phases:

1. Project Execution Phase (CAPEX Phase): Temporary, high-intensity mobilization lasting 6 to 12 months for Design, Procurement, Civil Works, Erection, and Commissioning.

Workforce Category	% Share	Head-count/ GW (Range)	Headcount/ GW	Key Functional Roles & Responsibili-ties	Core Skills & Qualifications
Blue-Collar / Shopfloor	85%	1,020-1,510	1,265	Civil works and piling; mounting structures; module installation and stringing; DC cabling; AC electrical works; switchyard and substation erection; testing and commissioning support; safety and material handling.	ITI/diploma in electrical, civil or mechanical trades; solar installation; DC/AC cabling; electrical testing; transformer and switchgear installation; working-at-height and industrial safety.
White-Collar / Supervisory	15%	180-290	235	Design and engineering; PVsyst modelling; procurement and supply chain; project controls; finance, HR and administration; site management; quality and EHS; grid engineering; SCADA and commissioning management.	B.Tech/B.E.or relevant diploma; solar PV design; PVsyst; project management; electrical and grid engineering; quality assurance; SCADA; EHS.

2. Operations & Maintenance Phase (OPEX Phase): Long-term, permanent/steady-state employment for the 25-year lifecycle of the solar asset.

Category	Proportion	Headcount/ GW (Range)	Empirical Baseline	Key Functional Roles & Responsibilities	Core Skills & Qualifications
Blue-Collar / Shopfloor	75%	90-135	113	SCADA operators; preventive and corrective maintenance technicians; module cleaning and vegetation management workers; robotic cleaning operators; security guards and patrol workforce.	ITI/diploma in electrical, electronic or mechanical trades; solar PV O&M; troubleshooting; inverter and transformer maintenance; SCADA monitoring; robotic cleaning equipment; safety procedures.
White-Collar / Supervisory	25%	30-45	38	Plant and asset management; generation performance monitoring; maintenance planning; reliability improvement; site supervision; quality assurance; security management; finance, HR, regulatory compliance and administration.	B.Tech/B.E.in relevant disciplines; solar plant operations; SCADA and data analytics; maintenance planning; asset management; regulatory compliance; contract management.

Table 17: Detailed Breakup by Function & Level (EPC Phase)

Department / Function	Total Workforce	White-Collar	Blue-Collar
Design, Engineering & PVsyst Modelling	25 - 40	25 - 40	0
Procurement, SCM & Vendor Management	20 - 30	20 - 30	0
Project Controls, Finance, HR, Legal & Admin	35 - 50	30 - 40	5 - 10 (Drivers/Admin Helpers)
Site Management, Quality & Safety (EHS)	60 - 90	45 - 60	15 - 30 (Safety Stewards)
Civil Works, Piling & Mounting Structures	450 - 700	20 - 30 (Site Engineers)	430 - 670 (Riggers, Mason, Laborers)
DC Electricals, Module Mounting & Stringing	400 - 600	20 - 30 (Electrical Leads)	380 - 570 (Stringers, Cable Jointers)
AC Power, Substation (PSS/GSS) & Grid Evacuation	150 - 220	20 - 30 (Grid Engineers)	130-190(Switchyard Electricians/Fitters)
Testing, SCADA & Pre-Commissioning	40 - 70	20 - 30	20 - 40
TOTAL (EPC Peak)	1,200 - 1,800	180 - 290 (16%)	1,020 - 1,510 (84%)

Phase 2: Asset Management & O&M Phase (25-Year Operational Phase)

(Permanent/Ongoing deployment per 1 GW of operational portfolio)

Once commissioned, a 1 GW solar asset requires significantly less workforce due to central SCADA monitoring, robotic cleaning, and automated string monitoring.

Table 18: Detailed Breakup by Function & Level (O&M Phase)

Department / Function	Total Headcount	White-Collar (Asst. Manager & Above)	Blue-Collar (Technicians, Guards, Cleaners)
Plant Operations, SCADA & Asset Management	12 - 18	8 - 12 (Plant Head, Shift AMs)	4 - 6 (Control Room Operators)
Preventive & Corrective Maintenance	25 - 40	6 - 10 (Maintenance Managers)	19 - 30 (Technicians, Electricians)
Module Cleaning & Vegetation Management	35 - 50	2 - 4 (Site Supervisors)	33 - 46 (Robotics Operators / Grass Cutters)
Security & Yard Monitoring	30 - 50	2 - 3 (Security Head / Assistant Managers)	28 - 47 (Guards / Patrolmen)
Finance, Accounts, HR, Regulatory & Admin	10 - 15	8 - 12	2 - 3
TOTAL (Operational Phase)	120 - 180	30 - 45 (25%)	90 - 135 (75%)

Payroll & Employer Split: EPC Company vsSubcontractors

The utility solar power generation sector in India operates on a lean corporate team with specialized subcontractor model.

Table 19: EPC Construction Phase Payrolls

Employment Arrangement	Workforce Share	Workforce/GW (Range)
EPC Direct Payroll (Core Management & Leads)	10-15%	120 - 270
Subcontractors & Workforce Agencies	85 - 90%	1,080 - 1,530
Total EPC Workforce	100%	1,200 - 1,800

1. On rolls of the Primary EPC / IPP Developer (10% - 15%)
    - ✦ Profile: White-collar professionals, senior project directors, lead civil/electrical engineers, procurement heads, finance managers, quality leads, and site safety in-charges.
2. On rolls of Subcontractors & Labor Agencies (85% - 90%)
    - ✦ Profile: Piling contractors, tracker/fixed-tilt structural erectors, cabling contractors, pooling substation (PSS) turnkey erection crews, security agencies, and local civil workforce.

Key Industry HR Insights in India

1. Rise of Dry-Cleaning & Robotic O&M: Survey indicated that, module washing required 80-120 manual blue-collar workers per GW.With water scarcity in solar hubs like Rajasthan and the adoption of autonomous robotic cleaning, manual labor in O&M has dropped by over 50%.
2. Substation & High-Voltage Skill Shortage: White-collar engineers proficient in 220 kV / 400 kV pooling switchyards and grid compliance (CEIG approvals) carry high market premiums due to rapid capacity additions across Indian power corridors.
3. Local Hiring Preferences: (requiring local hiring preferences) mean that up to 70% of blue-collar contractor roles during construction are sourced locally from villages surrounding the solar park site.

Operations and maintenance are essential for sustaining the performance, reliability and safety of renewable energy assets.The workforce in this segment includes technicians, electrical and mechanical engineers, site supervisors, asset managers, design and engineering workforce, quality professionals and specialists in performance monitoring.

The survey findings indicate that workforce requirements extend beyond routine plant maintenance. Workforce are also required for planning and coordination, design and engineering, procurement, construction supervision, quality assurance, asset management and performance optimisation.

Key skills required for renewable energy project operations include:

- ✦ Preventive and corrective maintenance.
- ✦ Electrical systems, equipment inspection and fault diagnosis.
- ✦ Plant performance monitoring and data analysis.
- ✦ Safety procedures and emergency response.

- Asset management and maintenance planning.
- Design, engineering and construction supervision.
- Digital monitoring, AI-based alerts and performance analytics.
- Identification of equipment faults and implementation of corrective actions.

The workforce structure in renewable energy project development and implementation varies depending on the scale of operations, project capacity, location of the project and the extent of in-house and outsourced activities.Workforce may be distributed across corporate offices, headquarters, project sites, and field operations.An indicative workforce requirement of approximately 200 workforce per GWp has been reported for renewable energy project implementation, with workforce deployed across engineering, supervision, technical operations, and support activities.For a 100 MW project, workforce deployment may include in-house workforce, technicians, supervisors, and unskilled workers.Actual workforce requirements vary depending on project complexity, construction activities, contracting arrangements, and the scope of implementation.

The survey also highlights the importance of practical, site-based learning.The fresh/ new employees undergo approximately 3 months of on-site training and require around 2 years to develop the experience and judgement needed to take independent responsibility for complex tasks.

Attrition rate of employees also reported as a concern in project operations and O&M.Reported rates included 12-13% in one operational setting and 20-30% in another workforce context.Retention measures mentioned during consultations included site allowances, food and accommodation support, performance incentives, bonuses and opportunities for career progression.

The use of AI-based monitoring tools is improving the identification of abnormal operating conditions and support maintenance planning.However, the survey highlighted that human intervention remains important for validating alerts, diagnosing root causes and implementing corrective actions.Training is therefore combining digital skills with practical engineering knowledge and field experience.



Figure 24: Solar Utility Scale Plan

4.3. Emerging Technologies

The solar industry is undergoing technological changes across manufacturing, project execution and plant operations.The survey consultations highlighted the growing importance of advanced cell technologies, manufacturing automation, digital monitoring, AI and ML applications, and improved inspection and quality-control systems.

These developments are changing the competencies required of both new recruits and experienced workforce.In addition to foundational electrical, mechanical and manufacturing skills, workers

increasingly need to interpret process data, operate automated equipment, troubleshoot digital systems and adapt to changing production technologies.

4.3.1. TOPCon Solar Cell Technology

Tunnel Oxide Passivated Contact (TOPCon) is an advanced crystalline silicon solar cell technology that requires specialised process knowledge and precise control of manufacturing parameters.Its adoption increases the importance of training in equipment operation, process monitoring, quality assurance and defect identification.

The survey identified TOPCon as part of the ongoing expansion of solar cell manufacturing.

The key skills required for TOPCon manufacturing include:

- Understanding of the cell manufacturing process and production parameters.
- Operation and monitoring of specialised manufacturing equipment.
- Process control and identification of production deviations.
- Quality inspection, testing and defect analysis.
- Equipment maintenance and troubleshooting.
- Interpretation of production data and process performance indicators.
- Compliance with standard operating procedures and safety requirements.

The workforce must be able to maintain consistent process conditions and identify deviations that may affect cell efficiency, quality and production yield.Engineers and experienced technicians require deeper process knowledge, while operators need practical training in equipment operation, routine inspection and response to abnormal conditions.

The expansion of advanced cell manufacturing also creates a need for specialised training infrastructure.Technical institutions and industry training centres can support this requirement through practical modules, equipment demonstrations, simulation-based learning and supervised exposure to manufacturing processes.

Training programmes should be periodically updated to reflect changes in cell technology, equipment configuration and manufacturing practices.Collaboration between manufacturers, equipment suppliers and academic institutions can help ensure that training remains aligned with industrial requirements.

4.3.2. Perovskite Solar Cells

Perovskite solar cells represent an emerging area of photovoltaic research and technology development. Their potential applications and future manufacturing requirements may create new skill needs in materials science, device fabrication, characterisation, quality testing and process development.

The survey information available for this chapter does not provide sufficient specific evidence to quantify current workforce deployment, recruitment requirements or training gaps related to perovskite solar cells.Accordingly, no company level or industry-wide workforce estimate is shown for this technology.

As technology develops, potential competency areas may include:

- Materials science and photovoltaic device engineering.
- Thin-film deposition and controlled fabrication processes.
- Laboratory testing and material characterisation.
- Device stability, durability and performance assessment.

- Quality assurance and process development.
- Research, development and technology scale-up.

These areas should be treated as prospective skill requirements rather than confirmed survey findings. Further consultation with research institutions, technology developers and relevant manufacturing stakeholders would be required to assess the status of the technology and determine the scale and nature of future workforce demand.

4.3.3. AI and ML in Solar O&M

Artificial intelligence and machine learning are increasingly relevant to renewable energy operations through performance monitoring, fault detection, predictive maintenance and analysis of operational data.Automated systems are supporting the identification of abnormal operating conditions and help prioritise maintenance activities.

The survey consultations highlighted the use and growing relevance of AI-based monitoring and automated inspection systems in manufacturing and renewable energy operations.However, the effective use of these technologies requires workforce who understand both the underlying engineering systems and the digital tools used to monitor them.

The key skill areas include:

- Data collection, validation and interpretation.
- Monitoring of plant performance indicators.
- Identification of abnormal operating conditions.
- Understanding AI-generated alerts and recommendations.
- Fault diagnosis and root-cause analysis.
- Predictive maintenance and maintenance planning.
- Automated image inspection and defect classification.
- Integration of digital monitoring systems with operational procedures.

In solar module manufacturing, AI-enabled inspection and automated optical inspection are supporting in defect identification and quality control.In renewable energy plant operations, digital monitoring tools assist in identifying performance deviations and potential equipment faults.

Nevertheless, automated alerts do not eliminate the need for technical judgement.Workforce must be capable of verifying alerts, identifying underlying causes and implementing suitable corrective actions. Training should therefore integrate digital literacy, electrical and mechanical fundamentals, data interpretation and hands-on troubleshooting.

A structured approach to AI and ML training should include basic digital skills for technicians, specialised analytical skills for engineers and advanced applications for workforce responsible for system integration, performance optimisation and technology development.

4.4.Future Workforce and Skill Requirements

The anticipated expansion of solar PV manufacturing and renewable energy deployment is expected to increase demand for workforce across production, maintenance, engineering, quality assurance and project operations.The nature of this demand will depend on the pace of capacity expansion, technology adoption, equipment automation and the development of domestic manufacturing capabilities.

The survey findings suggest that future workforce planning should address both the number of workforce required and the competencies needed to perform increasingly specialised tasks.Recruitment alone

may not be sufficient where workers lack practical exposure to industrial equipment, advanced manufacturing processes or digital monitoring system

Table 20: Projected workforce required by 2030

Segment	Projected Capacity (Name plate)	Estimated Workforce by 2030			
	March 2030	Blue Collar	White Collar	Blue Collar	White Collar
Manufacturing	GW	HR/GW	HR/GW	Total HR	Total HR
Module	280	280 - 390	70 - 110	60,000* - 71,000	13,000* - 20,000
Cell	170	340 - 480	110 - 170	57,800 - 81,600	18,700 - 28,900
Ingot and wafer	70	210 - 250	130 - 150	14,700 - 17,500	9,100 - 10,500
Polysilicon	38	180 - 250	70 - 100	6,840 - 9,500	2,660 - 3,800
Total Human Resource				**1,39,340 - 1,79,600**	**43,460 - 63,200**
Segment	**Installed Capacity[28]**	**Estimated Workforce by 2030**			
Power Generation	**March 2030**	**Blue Collar**	**White Collar**	**Blue Collar**	**White Collar**
	GW	**HR/GW**	**HR/GW**	**Total HR**	**Total HR**
Ground Mounted Solar and Hybrid (Solar Component)	200	1,100 - 1,650	210 - 330	44,500 - 66,500	8,500 - 13,500
Decentralised - (Off-grid & KUSUM-B)	25	1,500 - 2,000	250 - 300	5,500 - 7,500	850 - 1,050
RTS (C&I and Residential)	75	2,200 - 2,800	200 - 250	26,500 - 33,500	2,400 - 3,000
Total Human Resource	300			**76,500 - 1,07,500**	**12,000 - 17,500**

**For module manufacturing 65% of name plate capacity is considered as operational capacity to project the workforce deployment*

***** For power generation segment, the estimated projected workforce for 2030 has been calculated considering only annual installation in the last financial year (FY-26).Additional workforce is considered for operation and maintenance of additional ground mounted installation from October 2026 to March 2030.*

The installed power generation capacity estimated for 2030 has been arrived by referring the REPORT ON OPTIMAL GENERATION CAPACITY MIX FOR 2029-30 Version 2.0, and considering the actual physical achievement as on September 2026 (MNRE)

[28] https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/09/2023090113868365 93.pdf

4.4.1. Manufacturing Workforce

Future manufacturing requirements are likely to include a combination of entry-level operators, experienced technicians, process engineers, maintenance specialists, quality professionals and managers.

Priority skill areas include:

- Ingot and wafer production, material processing and equipment operation.
- Solar cell process control, testing and quality assurance.
- Module assembly, stringing, printing and automated inspection.
- Electrical, mechanical and instrumentation maintenance.
- Automation, robotics and control systems.
- Manufacturing software, production monitoring and data analysis.
- Equipment troubleshooting and process optimisation.
- Research and development for advanced manufacturing technologies.

Survey responses also indicated the need for graduates with specialised technical qualifications, including postgraduate and doctoral-level expertise for research and development activities.This requirement is particularly relevant where manufacturers seek to improve process performance, develop indigenous technologies and reduce dependence on external technical support.

4.4.2. Renewable Energy Project Development and O&M

Future project development and O&M requirements will extend across design and engineering, project planning, construction supervision, quality assurance, asset management and plant performance optimisation.

Key competencies include:

- Electrical system design and engineering.
- Project planning and coordination.
- Construction supervision and quality control.
- Preventive and predictive maintenance.
- Plant monitoring and performance analysis.
- Digital tools and AI-assisted diagnostics.
- Occupational health and safety.
- Asset management and lifecycle planning.

The survey indicated that practical exposure is important for engineering graduates entering project-based roles.Structured internships, supervised site assignments and graduate training programmes can help bridge the gap between academic knowledge and workplace requirements.

4.4.3. Training and Certification Requirements

The survey highlighted the need for a more structured system of training and competency development. Training arrangements should be tailored to diverse workforce levels rather than relying on a single programme for all employees.

Workforce category	Priority training areas
ITI and diploma workforce	Equipment operation, electrical and mechanical fundamentals, routine maintenance, safety and quality checks
Engineering graduates	Process engineering, automation, troubleshooting, production analysis, design and project execution
Experienced technicians and supervisors	Advanced diagnostics, equipment reliability, team supervision, quality improvement and digital systems
Managers and senior professionals	Workforce planning, technology adoption, operational performance, productivity and strategic skill development
Research and development workforce	Advanced cell technologies, materials science, process development, data analysis and indigenous technology development

Training programmes should combine classroom instruction with practical exercises, equipment demonstrations, supervised industrial assignments and competency assessments.Short induction programmes can provide basic orientation, but specialised roles require longer training periods and continuing skill development.

The survey also highlighted the potential value of Recognition of Prior Learning (RPL) for workers who have acquired skills through experience but lack formal certification.Appropriate assessment and certification mechanisms could help recognise existing competencies and identify areas where additional training is required.

4.4.4.Industry-Academia Collaboration

Collaboration between industry and academic institutions can improve the relevance of technical education and provide students with exposure to current manufacturing and renewable energy practices.

Potential areas of collaboration include:

- Curriculum development aligned with industry requirements.
- Active participation of industry expert member to the academia for sharing the lecture and talking about the key challenges.
- Establishment of specialised solar manufacturing and O&M laboratories.
- Equipment access for practical training.
- Industrial internships and apprenticeship programmes.
- Joint training modules for advanced cell technologies.
- Faculty development and industry expert lectures.
- Research projects addressing equipment, process and performance challenges.
- Development of training materials for AI, ML and automation.

The survey also highlighted the need to strengthen domestic capabilities in manufacturing equipment, software and technical support.Partnerships involving industry, academic institutions, training providers and government agencies can support the development of specialised expertise and reduce gaps between education and industrial practice.

4.4.4.1.Challenges

The discussions highlighted several challenges in strengthening the renewable energy skill development ecosystem in India.A key challenge is the gap between existing engineering curricula and evolving industry requirements, particularly in terms of practical exposure to industrial processes, emerging technologies, and real-world applications.Limited access to advanced laboratories, specialised equipment, and research infrastructure also affects students' practical learning and research capabilities.Furthermore, industry-supported internships, appropriate stipends, faculty training opportunities, and industry-defined research projects require greater participation from industry.Confidentiality requirements, including Non-Disclosure Agreements (NDAs), can create difficulties for students in preparing and submitting academic theses based on industrial research.Although specialised solar training programmes and training centre's have been established, further strengthening of practical training infrastructure in ITIs and engineering institutions is required to ensure that students acquire industry-relevant skills and are prepared for the evolving requirements of the renewable energy sector.

4.4.4.2.Recommendations

To address these challenges, stronger and more structured collaboration between renewable energy industries, academic institutions, and skill development organisations should be promoted.

Engineering curricula should be reviewed periodically in consultation with industry representatives to incorporate current industry requirements, practical applications, and emerging technologies, including Artificial Intelligence (AI) and Machine Learning (ML) in renewable energy.Industries should support the establishment of advanced laboratories and provide surplus equipment, sample solar cells, and other relevant instruments to improve hands-on learning.

Structured internships with appropriate stipends, regular industry interactions, guest lectures, and faculty training opportunities should be encouraged to enhance practical knowledge and industry readiness.

Industries should also share relevant research problem statements and provide the necessary infrastructure for industry-oriented research.Appropriate confidentiality arrangements should be developed to protect industrial information while enabling students to fulfil their academic requirements.Furthermore, practical training facilities equipped with relevant industrial equipment should be strengthened in ITIs and engineering institutions, while leveraging existing training networks to expand specialised renewable energy training and improve the availability of skilled workforce across the renewable energy value chain.

4.4.5. Workforce Retention and Career Progression

Workforce retention will remain important as manufacturing capacity expands and demand for experienced workforce increases.Survey responses identified relocation, limited local workforce availability, contractual employment, early attrition and competition for experienced workers as factors affecting workforce continuity.

Reported retention measures include performance-based incentives, bonuses, accommodation and food support, transport facilities, subsidised meals, employee recognition, career progression and transfers closer to employees' home locations.

Structured career pathways can also improve retention by providing employees with opportunities to progress from operator and technician roles to senior technical, supervisory and managerial positions. Internal promotion, cross-functional training and opportunities to acquire specialised skills can help retain institutional knowledge.

Workforce planning should therefore integrate recruitment, training, certification, performance assessment and retention.This would support the development of a stable workforce capable of meeting changing technical requirements.

4.5.State-wise Findings

Table 21: Major states with current operational solar manufacturing capacity and projected capacity by 2030

State / UT	Current Operational Capacity	Projected Operational Capacity by 2030
Gujarat	**Module:** 35.0 - 38.0 GW	**Module:** 45.5 - 48.8 GW *(70-75 GW Nameplate)*
(Mundra, Surat, Kosamba, Dholera, Sanand)	**Cell:** 12.0 - 14.0 GW	**Cell:** 26.0 - 29.3 GW *(40-45 GW Nameplate)*
	Wafer/Ingot: 0.90 GW *(2.0 GW Nameplate)*	**Wafer/Ingot:** 19.5 - 22.8 GW *(30-35 GW Nameplate)*
	Polysilicon: Commercial pilot / Nil	**Polysilicon:** 13.0 - 16.3 GW *(20-25 GW Nameplate)*
Telangana	**Module:** 8.0 - 10.0 GW	**Module:** 11.7 - 13.0 GW *(18-20 GW Nameplate)*
(Fab City, Maheshwaram, Raviryal)	**Cell:** 14.0 - 15.0 GW	**Cell:** 16.3 - 19.5 GW *(25-30 GW Nameplate)*
	Wafer/Ingot: Nil	**Wafer/Ingot:** 6.5 - 7.8 GW *(10-12 GW Nameplate)*
	Polysilicon: Nil	**Polysilicon:** Nil
Andhra Pradesh	**Module:** 6.0 - 7.5 GW	**Module:** 9.8 - 11.7 GW *(15-18 GW Nameplate)*
(Sri City, Chittoor, Visakhapatnam)	**Cell:** 3.0 - 4.0 GW	**Cell:** 7.8 - 9.8 GW *(12-15 GW Nameplate)*
	Wafer/Ingot: Nil	**Wafer/Ingot:** 5.2 - 6.5 GW *(8-10 GW Nameplate)*
	Polysilicon: Nil	**Polysilicon:** 3.3 - 4.6 GW *(5-7 GW Nameplate)*
Tamil Nadu	**Module:** 7.0 - 8.5 GW	**Module:** 11.7 - 14.3 GW *(18-22 GW Nameplate)*
(Oragadam, Gangaikondan, Sriperumbudur)	**Cell:** 2.5 - 3.5 GW	**Cell:** 6.5 - 7.8 GW *(10-12 GW Nameplate)*
	Wafer/Ingot: Nil	**Wafer/Ingot:** 5.2 - 6.5 GW *(8-10 GW Nameplate)*
	Polysilicon: Nil	**Polysilicon:** Nil
Rajasthan	**Module:** 5.5 - 6.5 GW	**Module:** 7.8 - 9.8 GW *(12-15 GW Nameplate)*
(Jaipur, Alwar, Bhiwadi, Bikaner)	**Cell:** 1.0 - 1.5 GW	**Cell:** 3.9 - 5.2 GW *(6-8 GW Nameplate)*
	Wafer/Ingot: Nil	**Wafer/Ingot:** 2.6 - 3.3 GW *(4-5 GW Nameplate)*
	Polysilicon: Nil	**Polysilicon:** Nil
Maharashtra	**Module:** 3.5 - 4.5 GW	**Module:** 6.5 - 7.8 GW *(10-12 GW Nameplate)*
(Nagpur/Butibori, Chakan, Pune)	**Cell:** Under commissioning	**Cell:** 5.2 - 6.5 GW *(8-10 GW Nameplate)*
	Wafer/Ingot: Nil	**Wafer/Ingot:** 6.5 GW *(10 GW Nameplate)*
	Polysilicon: Nil	**Polysilicon:** Nil

State / UT	Current Operational Capacity	Projected Operational Capacity by 2030
Odisha	**Module:** 1.0 - 2.0 GW	**Module:** 5.2 - 6.5 GW *(8-10 GW Nameplate)*
(Infovalley, Dhenkanal, Gopalpur)	**Cell:** Under construction	**Cell:** 6.5 - 7.8 GW *(10-12 GW Nameplate)*
	Wafer/Ingot: Nil	**Wafer/Ingot:** 3.3 - 4.6 GW *(5-7 GW Nameplate)*
	Polysilicon: Nil	**Polysilicon:** 3.25 GW *(5 GW Nameplate)*
Other States & Pipeline Allocations	**Module:** 36.84 GW	**Module:** 69.8 - 76.5 GW
(UP, MP, Karnataka, WB, NCR & up-coming SEZs)	**Cell:** 3.25 GW	**Cell:** 24.6 - 35.3 GW
	Wafer/Ingot: Nil	**Wafer/Ingot:** Nil
	Polysilicon: Nil	**Polysilicon:** 0.55 - 5.15 GW
Total Operational Footprint (India)	**Module: 102.84 GW** *(45% of 228.54 GW)*	**Module: 182.00 GW** *(65% of 280.0 GW)*
	Cell: 15.75 GW *(45% of 35.00 GW)*	**Cell: 110.50 GW** *(65% of 170.0 GW)*
	Wafer/Ingot: 0.90 GW *(45% of 2.00 GW)*	**Wafer/Ingot: 45.50 GW** *(65% of 70.0 GW)*
	Polysilicon: 0.00 GW*(45% of 0.00 GW)*	**Polysilicon: 24.70 GW** *(65% of 38.0 GW)*

**Operational capacity is calculated considering the capacity utilization of 45% (current) and 65% (projected)*

Table 22: State-wise Estimated Workforce for solar manufacturing by 2030

State / UT & Manufacturing	Estimated Blue-Collar Workforce	Estimated White-Collar Workforce	Total Estimated Workforce
Gujarat	28,015 - 42,800	9,490 - 15,370	37,505 - 58,170
Telangana	10,165 - 16,380	3,450 - 5,915	13,615 - 22,295
Andhra Pradesh	7,060 - 12,005	2,445 - 4,375	9,505 - 16,380
Tamil Nadu	6,580 - 10,945	2,210 - 3,875	8,790 - 14,820
Rajasthan	4,055 - 7,110	1,315 - 2,445	5,370 - 9,555
Maharashtra	4,955 - 7,790	1,870 - 2,940	6,825 - 10,730
Odisha	4,935 - 8,230	1,730 - 3,050	6,665 - 11,280
Other States & Pipeline Allocations (UP, MP, Karnataka, WB, NCR & upcoming SEZs))	36,765 - 36,310	9,990 - 10,130	46,755 - 46,440

By 2030, solar PV manufacturing across the key industrial hubs is projected to generate an aggregate workforce of 1.35-1.90 lakh personnel. Occupational distribution is heavily anchored by shopfloor operations, with blue-collar personnals comprising 74.7% (1.03-1.42 lakh) and white-collar professionals accounting for 25.3% (0.33-0.48 lakh). Geographically, Gujarat dominates domestic manufacturing employment, commanding 29.5% of the total workforce (37,505-58,170 personnel). Southern manufacturing clusters represent 26.4% of aggregate demand, led by Telangana (11.1%; 13,615-22,295), Andhra Pradesh (8.0%; 9,505-16,380), and Tamil Nadu (7.3%; 8,790-14,820). Western and eastern industrial centres account for another 15.5%, divided among Odisha (5.5%; 6,665-11,280),

Maharashtra (5.4%; 6,825-10,730), and Rajasthan (4.6%; 5,370-9,555). The remaining 28.7% of the manufacturing workforce (46,755-46,440 personnel) is distributed across other states, including NCR, Uttar Pradesh, Madhya Pradesh, West Bengal, and Karnataka.

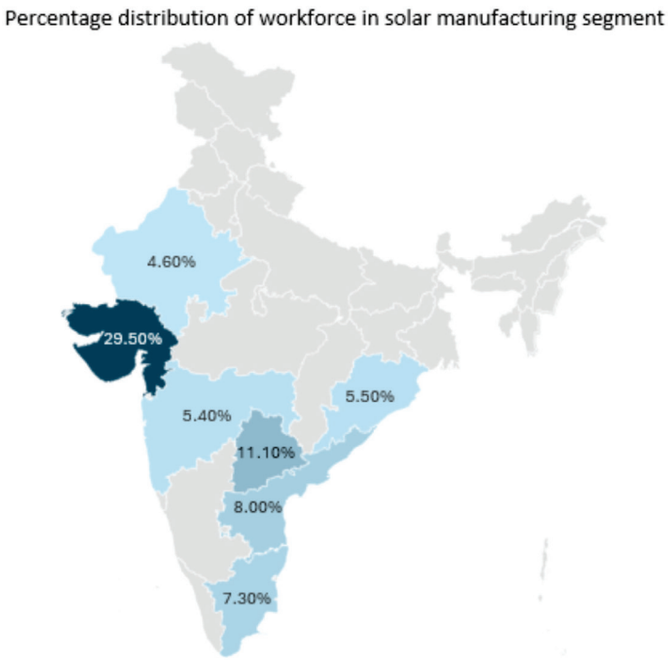


Figure 25: State wise percentage Distribution of workforce in solar

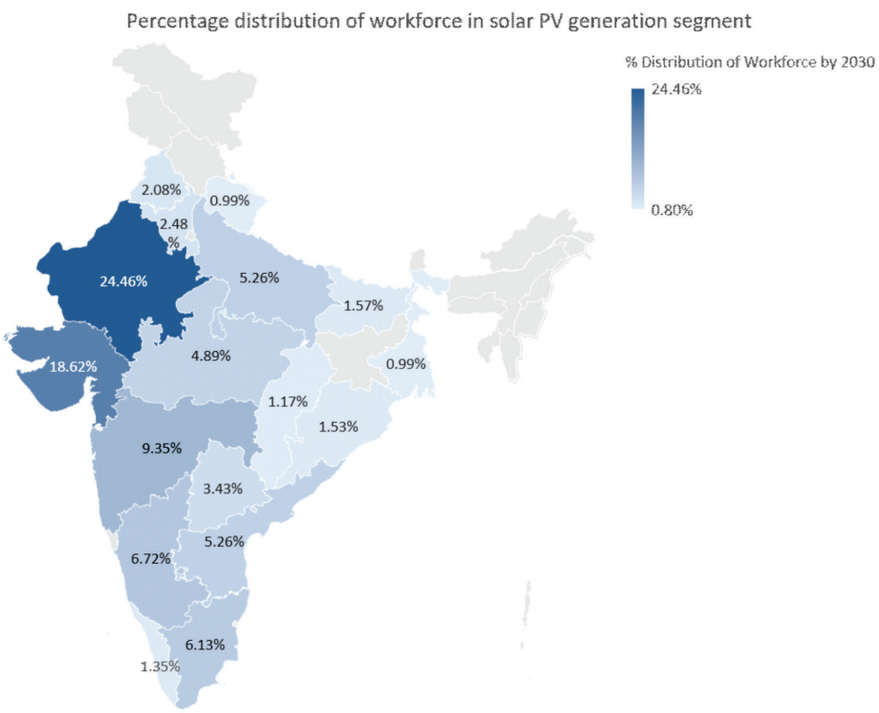


Figure 26: State wise percentage Distribution of workforce in solar PV generation

Table 23: State-wise Estimated Workforce for solar PV generation by 2030

State / Union Territory	Cumulative Installed Capacity (GW)	2030 Projected Target (GW)	Blue Collar requirement by 2030	White Collar requirement by 2030
Rajasthan	44.8	67 - 73	21,500	3,500
Gujarat	31.2	53 -57	16,900	2,800
Maharashtra	17.8	26 - 29	8,400	1,450
Karnataka	12.4	18.0 - 22.0	6,100	1,000
Tamil Nadu	11.6	16.0 - 20.0	5,500	900
Andhra Pradesh	9.4	15 - 17	4,900	800
Madhya Pradesh	8.6	14 - 16	4,600	700
Telangana	6.8	10 to 12	3,400	500
Uttar Pradesh	6.4	15.0 - 17.0	4,900	800
Haryana	4.1	7 to 9	2,500	400
Punjab	3.2	6 to 7	2,000	300
Kerala	2.1	4 to 5	1,400	200
Odisha	1.8	4 to 6	1,500	200
Chhattisgarh	1.4	3 to 5	1,200	200
West Bengal	1.35	2 to 4	900	100
Bihar & Jharkhand	1.8	4 to 6	1,500	200
Uttarakhand & HP	1.3	3 to 5	1,200	200
North-Eastern States	0.8	2 to 3	800	100
UTs (Delhi, J&K, Ladakh, etc.)	4.2	8 to 10	2,800	400
Total India	171.05	277 - 323	92,000	14,750

4.6.Recruitment and Skill Challenges

The survey consultations identified several interconnected challenges affecting recruitment, training, retention and workforce development across the solar industry value chain.These challenges are particularly relevant as manufacturing capacity expands and production systems become increasingly automated.

4.6.1. Limited Availability of Industry-Ready Candidates

Although ITI, diploma and engineering graduates are recruited for various technical positions, employers reported that new entrants often require additional practical training before they can independently operate equipment or undertake specialised assignments.

The gap is particularly relevant to advanced manufacturing processes, automation, equipment maintenance, quality control and renewable energy project execution.

Suggested approach: Strengthen practical training, apprenticeships, industry internships and competency-based assessments.Training curricula should reflect actual workplace requirements and provide exposure to relevant equipment and industrial procedures.

4.6.2. Limited Specialised Training Infrastructure

The consultations highlighted gaps in specialised training facilities for ingot and wafer manufacturing, solar cell production, module assembly, automated inspection and equipment troubleshooting.

Training institutions may not always have access to the machinery, software and laboratory facilities required to simulate current industrial processes.This can limit the practical exposure available to students and newly recruited workers.

Suggested approach: Establish industry-linked training centre's equipped with relevant machinery, inspection systems, automation tools and simulation facilities.Existing technical institutions could also be supported through shared equipment, industry-sponsored laboratories and practical training partnerships.

4.6.3. Dependence on Experienced Workforce

Advanced manufacturing and renewable energy operations require experienced technicians, engineers and supervisors who understand process requirements, equipment behaviour and fault diagnosis. Developing this expertise takes time, and the departure of experienced workforce can affect production continuity and knowledge transfer.

Some survey responses indicated that experienced employees are engaged to train newly recruited workforce, while others reported structured programmes involving specialised overseas trainers.

Suggested approach: Develop formal trainer programmes, standard operating procedures, documented troubleshooting guides and structured mentoring arrangements.Knowledge transfer should be embedded in routine workforce development rather than depending exclusively on individual employees.

4.6.4. Attrition and Workforce Retention

Employee turnover was identified as a challenge in manufacturing and project-based operations. Reported attrition levels varied across the survey responses, including approximately 9%, 12-13%, 20-30% and around 30% in diverse workforce contexts.

Factors identified during consultations included relocation, contractual employment, limited local workforce availability, early departures after recruitment and the difficulty of replacing trained workforce.

Suggested approach: Strengthen induction, career progression, employee engagement and skill-based incentives.Employers may also consider accommodation, transport, meals, recognition programmes and opportunities for employees to work closer to their home locations, where feasible.

4.6.5. Workforce Planning for Automated Manufacturing

Increasing automation is changing the composition of manufacturing jobs.While automated production lines may reduce certain manual activities, they increase the importance of equipment monitoring, fault diagnosis, preventive maintenance, data interpretation and quality analysis.

The consultations highlighted the need for employees who can work effectively with stringers, printing systems, robotics, automated inspection and digitally controlled equipment.

Suggested approach: Update training curricula to include automation, robotics, programmable control systems, machine diagnostics, digital inspection and data-based quality management.Existing workers should also receive periodic upskilling as production equipment and processes evolve.

4.6.6. Gaps in Digital and Advanced Technical Skills

AI, ML, AOI and digital monitoring systems are becoming more relevant to solar manufacturing and O&M.However, their effective application depends on employees being able to interpret system outputs and understand the engineering conditions underlying the data.

The consultations indicated that AI-generated alerts may require human verification and intervention to identify root causes and determine corrective actions.

Suggested approach: Integrate digital literacy and data interpretation into technical training.Advanced modules should cover predictive maintenance, automated defect detection, performance analytics and the integration of digital tools with conventional engineering practices.

4.6.7. Dependence on Imported Equipment and Technical Support

Survey participants identified dependence on imported manufacturing machinery, proprietary software and external technical support as a major concern.There is an immediate need to develop domestic capabilities in this field.Extremely limited local expertise in equipment upgrades, specialised troubleshooting and software integration exist at present.

Suggested approach: Encourage collaboration among equipment manufacturers, domestic technology developers, research institutions and industry.Training programmes should include equipment diagnostics, software operation, maintenance, system integration and the development of indigenous technical capabilities.

4.6.8. Challenges in Renewable Energy Project Locations

Renewable energy projects may be in areas where access to skilled workforce, training providers and support infrastructure is limited.Site-based positions can also involve relocation, accommodation requirements and the need for specialised safety training.

The survey indicated that new graduates may need extended practical exposure before they can independently manage technical responsibilities.Some reported arrangements include approximately 3 months of on-site training, while other consultations indicated that it may take around 2 years for graduates to develop sufficient experience for independent responsibility in certain roles.

Suggested approach: Introduce structured graduate training programmes combining classroom instruction, site assignments, mentoring, safety training and competency assessments.Training plans should be adapted to the technical complexity of the role and the operating conditions of each project.

4.6.9. Need for Industry-Aligned Curriculum and Certification

The consultations highlighted the need to strengthen the alignment between academic education, vocational training and the requirements of the solar industry.Existing programmes may not provide sufficient exposure to advanced manufacturing, specialised equipment, digital monitoring and practical troubleshooting.

There is also an opportunity to recognise the competencies of workers who have acquired relevant skills through experience but lack formal certification.

Suggested approach: Develop industry-aligned curricula, modular certification programmes, apprenticeship pathways and Recognition of Prior Learning (RPL) mechanisms.Training providers should work with employers to define competency standards and update learning content.

4.6.10.Limited Awareness of Solar Industry Career Opportunities

The consultations indicated that awareness of career opportunities in renewable energy manufacturing and related technical occupations may be limited among students and potential workers, particularly in some Tier 2 and Tier 3 locations.

This can affect recruitment pipelines and limit access to suitable candidates for technical positions.

Suggested approach: Strengthen career guidance, outreach programmes, industry visits, internships and technical demonstrations through ITIs, polytechnics, schools and engineering institutions. Information on occupational roles, required qualifications, training opportunities and career progression should be made more accessible to prospective candidates.

4.7.Summary and Recommendations

The survey findings indicate that workforce development is a critical requirement for sustaining the expansion of solar PV manufacturing and renewable energy deployment in India.The challenges extend beyond the availability of workers and include specialised technical skills, practical training, retention, digital competencies and access to industry-aligned training infrastructure.

The key recommendations are summarised below.

Priority area	Recommended action
Specialised manufacturing skills	Develop training programmes for ingot and wafer production, cell manufacturing, module assembly and advanced inspection.
Practical training infrastructure	Establish industry-linked laboratories, training centre's and equipment-based learning facilities.
Industry-academia collaboration	Align ITI, diploma and engineering curricula with current manufacturing and renewable energy requirements.
Workforce certification	Expand competency-based assessments, modular certification and Recognition of Prior Learning.
Advanced technologies	Introduce training in TOPCon, automation, robotics, AI, ML, AOI and digital monitoring, as relevant to each occupational role.
Trainer development	Establish programmes for developing qualified trainers, mentors and technical specialists.
Workforce retention	Strengthen career pathways, employee engagement, skill-based incentives and location-specific support measures.
Project-based training	Provide structured on-site training, mentoring and safety instruction for renewable energy project workforce.
Domestic technical capability	Strengthen industry and research collaboration for equipment maintenance, software capability and indigenous technology development.
State-level planning	Assess workforce demand, training capacity and recruitment gaps using consistent state-wise data.

A coordinated approach involving industry, technical institutions, training providers and government agencies will be important to address these challenges.Workforce planning should be linked to manufacturing expansion and renewable energy deployment, with training programs designed around clearly defined occupational competencies.

The overall objective should be to create a workforce that is technically proficient, adaptable to emerging technologies and capable of supporting the quality, productivity, reliability and long-term growth of India's solar industry.

Table 24: Emerging Solar Technologies and Skill Requirements

Technology	Primary Application	Technology Trend	Key Skill Requirement
Topcon solar cells	Cell and module manufacturing	Rapid commercial adoption	Cell processing, equipment operation, process optimisation, quality control
Heterojunction Technology (HJT)	High-efficiency PV modules	Increasing industrial adoption	Thin-film deposition, process control, cell characterisation
Perovskite PV	Advanced PV and tandem modules	Emerging / R&D to early commercialisation	Materials science, device fabrication, laboratory characterisation
Perovskite-silicon tandem	Ultra-high-efficiency PV	Advanced emerging technology	Tandem device engineering, materials, encapsulation and reliability
Bifacial PV	Utility-scale and commercial projects	Increasing deployment	Yield modelling, albedo assessment, tracker optimisation
Floating solar	Reservoirs and water bodies	Growing deployment	Floating structures, anchoring, electrical safety, marine/environmental assessment
Solar + BESS	Renewable integration and peak management	Rapidly expanding	Battery systems, EMS, power electronics, safety
Smart inverters	Grid-connected PV	Increasingly important	Power electronics, grid codes, controls, communication
AI/ML-based O&M	Asset management	Rapidly emerging	Data analytics, machine learning, fault diagnosis
Drone and robotic inspection	PV plant inspection	Increasing adoption	UAV operation, thermography, image analytics
Advanced manufacturing	Module/cell production	Increasing automation	Automation, robotics, PLC/ SCADA, process analytics
Digital twins	Asset management	Emerging	Modelling, simulation, data integration
Green hydrogen integration	Solar-to-hydrogen systems	Emerging	Electrolysers, energy management, system integration
PV recycling	End-of-life management	Increasing importance	Material recovery, waste management, circular economy



5.Training and Ecosystem Assessment

5.1.Existing Training System Assessment

5.1.1. China

China's modern vocational education system provides a state-directed model for integrating technical schooling with high-volume industrial manufacturing through its national policy of "Integration of Industry and Education" and structured school-enterprise cooperation. Under this framework, technical training is jointly delivered by specialized vocational and technical colleges and major industrial enterprises. Trainees alternate between classroom-based engineering fundamentals and on-site industrial apprenticeships under the modern apprenticeship system, serving simultaneously as technical students and enterprise apprentices. Training typically spans three years within higher vocational curricula, culminating in standardized evaluations under the national "1+X" Certificate System, which pairs formal academic diplomas with industry-recognized vocational skill qualifications[29].

The Chinese ecosystem is governed through coordinated execution led by the Ministry of Education, the Ministry of Human Resources and Social Security, regional development and reform commissions, industry associations such as the China Photovoltaic Industry Association, and leading clean-energy manufacturing conglomerates. Enterprise-based training follows national occupational skill standards paired with localized enterprise production lines, enabling immediate deployment into advanced cleanrooms, ingot casting facilities, and automated assembly operations. Certified dual-qualified instructors—who hold both academic teaching credentials and direct shopfloor engineering experience—along with designated master craftsman mentors, ensure high-throughput workforce readiness aligned with continuous technological iterations in the photovoltaic and advanced manufacturing sectors[30].

5.1.2.Germany

Germany's dual vocational education and training (VET) system provides a well-established model for integrating theoretical education with workplace learning.Under the dual system, training takes place at the company and vocational school.Apprentices are simultaneously employees of a company and learners in the vocational education system.Depending on the occupation, training lasts between two and three-and-a-half years and concludes with a recognized final examination.

The German system is supported through cooperation among government, federal states, companies, chambers and social partners.Company-based training follows defined training regulations and individual training plans, while vocational schools provide complementary theoretical knowledge. Qualified company trainers and vocational-school instructors contribute to maintaining training quality [31].

5.1.3. Singapore

Singapore's Skills Future model provides a relevant example of continuous, industry-driven skill development for the solar sector.Its flexible short-course approach can be applied to emerging solar roles such as PV system design, advanced PV technologies (Topcon/HJT), solar-plus-storage, battery energy storage systems, smart inverters, digital O&M, AI-based monitoring and drone-based inspection. Green-skills frameworks can also strengthen cross-functional capabilities in energy management, carbon accounting and sustainable procurement [32].

[29] Ministry of Education of the People's Republic of China, Implementation Plan for the National Vocational Education Reform, http://www.moe.gov.cn/jyb_xxgk/moe_1777/moe_1778/201902/t20190213_369223.html
[30] National Development and Reform Commission & Ministry of Education, Implementation Plan for Deepening the Integration of Industry and Education (2023–2025), https://www.ndrc.gov.cn/xxgk/zcfb/tz/202306/t20230613_1357064.html
[31] https://www.bibb.de/en/77213.php
[32] https://www.skillsfuture.gov.sg/

5.1.4. The United States of America

The United States has adopted a collaborative approach to solar workforce development through regional training networks, employer partnerships and industry-recognised systems.The U.S.Department of Energy supported the Solar Instructor Training Network and subsequently established the Solar Training Network to strengthen coordination among community colleges, vocational training institutions, employers and workforce development organisations.These initiatives focused on expanding access to solar-specific technical education, developing standardised training resources and improving pathways into solar-related occupations[33].

The training approach incorporates classroom instruction, practical laboratory exercises, instructor development and industry-oriented skill assessment.Regional training providers have supported curriculum development, train-the-trainer programmes and hands-on learning opportunities across solar installation and related technical activities.Collaboration between employers and training institutions helps align workforce competencies with industry requirements, providing a useful model for developing regional solar training ecosystems and strengthening employment-oriented skill development in India

5.1.5. Australia

Australia has adopted an industry-oriented approach to clean energy workforce development through nationally recognised vocational qualifications, competency-based training and industry accreditation. Registered training organisations provide structured theoretical and practical training, while industry accreditation frameworks support professional standards for solar PV and battery system designers and installers.

The training framework emphasises technical competencies, electrical safety, system design, installation and compliance with industry standards.Competency assessments include theoretical and practical evaluations, while continuing professional development and recognised certifications support workforce upskilling in emerging solar PV and energy storage technologies[34,35].

5.1.6. United Kingdom

The United Kingdom, particularly England, has adopted employer-led occupational standards and apprenticeship programmes that combine workplace learning with structured technical training. Short-duration apprenticeship units support targeted upskilling to address emerging industry skill requirements.

The Solar PV Installation and Maintenance Apprenticeship Unit, approved in 2026, provides focused training in installation, inspection, fault diagnosis and maintenance.It requires a minimum of 35 training hours, followed by practical competency assessment and employer validation.This model offers a relevant approach for India to develop modular, industry-aligned solar training programmes and strengthen workforce certification[36].

[33] https://www.energy.gov/cmei/systems/solar-training-network
[34] https://training.gov.au/resources
[35] https://saaustralia.com.au/
[36] https://skillsengland.education.gov.uk/apprenticeship-units/AU0007

Table 25: Comparative Overview of Global Skill Training and Assessment Models

Country / Framework	Training Model	Key Feature	Assessment Approach	Relevance to India
China	Integration of Industry and Education (Modern Apprenticeship)	School-enterprise cooperation, dual-qualified instructors	1+X Certificate System, performance-based evaluation	Rapid workforce scaling for gigafactories and upstream PV manufacturing clusters
Germany	Dual VET	Company,vocational school	Formal final examination	Strengthen apprenticeships and workplace learning
Australia	Industry-led clean-energy framework	Training Matrix	Accreditation and continuous competency	Digital credentials and lifelong competency development
USA	Regional training network	Employer-training-provider partnerships	Training and credentialing linked to employment	Regional skill ecosystems
Singapore	Skills Future Singapore (SSG) and Skills Framework	Industry-aligned competency-based training, modular upskilling and lifelong learning	Skills-based assessments and recognised certifications	Develop industry-aligned competency frameworks, modular training programmes and continuous workforce upskilling
UK	Modular apprenticeship units	Short, targeted upskilling	Practical skills test + employer validation	Rapid response to specific skill shortages

5.2.Alignment between Industry and Training Programs

The effectiveness of solar photovoltaic (PV) workforce development depends on the extent to which existing education and training programs align with evolving industry requirements.India has established a growing ecosystem of technical education, vocational training and renewable energy skill development through engineering institutions, polytechnics, Industrial Training Institutes (ITIs), the National Institute of Solar Energy (NISE), the Skill Council for Green Jobs (SCGJ) and initiatives such as the Surya Mitra Skill Development Program.These institutions and programs contribute to workforce development, particularly in solar PV installation, commissioning, basic electrical systems and operations and maintenance (O&M).However, the increasing technological complexity of solar PV systems necessitates continuous assessment and modernisation of training content, delivery mechanisms and competency standards.

Table 26: Solar PV Industry Skill Requirements and Training Alignment Gaps

Solar PV Segment	Industry Skill Require-ments	Existing Training Focus	Key Alignment Gaps
Solar Cell Manufacturing	TOPCon, HJT, diffusion, deposition, automation and process control	PV fundamentals, semiconductor principles and on the job industrial training	Limited access to advanced manufacturing equipment and process-specific training
Solar Module Manufacturing	Stringing, lamination, EL inspection, quality assurance and automated production	Manufacturing fundamentals, electrical testing and employer-led training	Greater need for automated production, defect analysis and reliability competencies
Solar Project Design	PVsyst, AutoCAD, electrical design, system optimisation and energy yield assessment	Electrical engineering and basic PV system design	Advanced modelling, simulation and hybrid system design
EPC and Installation	Site execution, mounting systems, DC/AC installation, testing and commissioning	Solar installation, electrical wiring and basic commissioning	Utility-scale commissioning, quality control and advanced safety
Grid Integration	Inverter control, protection systems, grid codes, power quality and BESS integration	Power electronics and electrical engineering fundamentals	Grid compliance, storage integration and advanced system controls
Operations and Maintenance	SCADA, thermography, fault diagnosis, performance analysis and predictive maintenance	Preventive maintenance and basic troubleshooting	Advanced diagnostics, data analytics and digital O&M
Rooftop and Agricultural Solar	Distributed PV installation, solar pumping, troubleshooting and customer service	Solar technician and installation programs	Application-specific maintenance, service delivery and field diagnostics

A significant area of concern is the difference between foundational technical knowledge imparted through conventional academic and vocational programs and the specialized competencies required across the contemporary solar value chain.While existing training program provide an important foundation in electrical engineering, solar system installation and maintenance, industry requirements increasingly extend to advanced solar cell manufacturing technologies such as Topcon and heterojunction (HJT), automated module production, sophisticated power electronics, grid-connected battery energy storage systems (BESS), and digitally enabled asset management.These emerging competencies require specialized laboratories, technology-specific instruction and practical exposure that may not be uniformly available across training institutions.

Furthermore, alignment challenges are evident in the availability of practical training infrastructure, industry participation in curriculum development and opportunities for structured workplace learning. Solar manufacturers and EPC companies increasingly require workforce capable of applying technical knowledge to real-world challenges involving process optimization, quality assurance, electrical safety, system commissioning, fault diagnosis and performance improvement.Limited access to operational solar facilities, advanced manufacturing equipment, simulation platforms and industry-standard software can restrict the development of these job-ready competencies.

Table 27: Solar Industry-Academia Collaborations

S.No	Collaborating Organizations	Key Focus Areas	Type of Collaboration
1	Waaree Energies - MIT World Peace University, Pune [37]	Manufacturing exposure, faculty development, research and technical training	Industry-Academia
2	Rayzon Solar - IIT Bombay (NCPRE) [38]	PV research, industry projects and student technical exposure	Industry-Academia Research
3	National Institute of Solar Energy (NISE) - IIT Bombay [39]	Solar research and renewable technology development	Research and Academic Collaboration
4	National Institute of Solar Energy (NISE) - IIT Roorkee [40]	Joint research, education, technology development and knowledge exchange	Research and Academic Collaboration
5	International Solar Alliance (ISA) - IIT Delhi [41]	Solar workforce training, research and knowledge exchange	Industry-Academia Research
6	National Institute of Solar Energy (NISE) - Surya Mitra Training Institutes [42]	Solar PV installation, commissioning, O&M and technician training	National Skill Development Program
7	Mahindra Susten - Centre of Excellence [43]	Solar technical training and practical infrastructure	Industry-Supported Skill Training

[37] https://mitwpu.edu.in/news/mit-wpu-signs-mou-with-waaree-energies-limited-to-advance-renewable-energy-education
[38] https://www.ncpre.iitb.ac.in/ncpre/highlights-link/IIT-Bombay-and-Rayzon-Solar-sign-an-MoU.php
[39] https://www.ncpre.iitb.ac.in/ncpre/highlights-link/memorandum-of-understanding-mou-signed-between-nise-and-iit-bombay.php
[40] https://www.pib.gov.in/PressReleasePage.aspx?PRID=2069125&lang=2&reg=48
[41] https://home.iitd.ac.in/show.php?id=419&in_sections=Press
[42] https://suryamitra.nise.res.in/Centers.html
[43] https://hrd.mnre.gov.in/suryamitra-dashboard/suryamitra-centers

5.3.Gaps in Training Infrastructure

The availability of industry-relevant training infrastructure is essential for developing a skilled workforce across the solar energy value chain.Key infrastructure gaps include limited access to practical training facilities, advanced manufacturing equipment, emerging PV technology laboratories, AI-enabled analytical platforms, digital simulation tools and specialised safety training systems.Strengthening training infrastructure through industry-academia collaboration, shared facilities and technology-oriented training centres can improve practical competencies, workforce readiness and alignment with evolving industry requirements.

Table 28: Training Infrastructure Gaps and Implications for Solar Workforce Development

Sl. No	Key Infrastructure Gap	Description and Implications
1	Limited Practical and Field-Based Training Facilities	Inadequate access to operational solar plants, demonstration systems and field-based training facilities may restrict practical competencies in installation, commissioning, troubleshooting and O&M
2	Inadequate Training Infrastructure in ITIs and Polytechnics	Limited availability of dedicated solar laboratories, rooftop installation mock-ups, PV training kits, inverters, testing instruments and safety equipment may affect the development of industry-relevant technical skills
3	Insufficient Advanced Laboratories in Engineering Institutions	Limited access to advanced PV laboratories, simulation platforms, solar cell characterisation equipment and performance testing facilities may constrain applied learning and exposure to emerging technologies
4	Inadequate Infrastructure for Emerging Solar Technologies	Limited training facilities for TOPCon, HJT, perovskite-silicon tandem technologies, bifacial modules and advanced energy storage integration may constrain the development of specialised technical competencies
5	Limited AI and Advanced Digital Training Infrastructure	Inadequate access to AI-based analytical platforms, machine learning tools, digital twins and relevant datasets may restrict practical training in solar generation forecasting, automated defect detection, performance optimisation and predictive maintenance
6	Insufficient Simulation, SCADA and Remote Monitoring Facilities	Limited availability of PV system design software, SCADA training systems, remote monitoring platforms and inverter simulation tools may affect competencies in system design, data analytics, fault diagnosis and digital O&M
7	Inadequate Off-grid and Floating Solar Training Facilities	Limited access to solar pumping systems, battery-integrated demonstration units, floating PV platforms and anchoring systems may restrict practical competencies in decentralised and specialised solar applications
8	Insufficient Safety, Testing and Quality Assurance Infrastructure	Inadequate availability of work-at-height training structures, electrical safety equipment, emergency response facilities, solar simulators, I-V tracers and electroluminescence testing systems may affect safety preparedness and technical competency assessment
9	Limited Industry-Academia Collaborative Training Infrastructure	Restricted access to industrial facilities, operational solar projects, industry-supported laboratories, internships and shared training centres may limit experiential learning and exposure to current industry practices



6 Impacts of Addressing Skill Gap

6.1. Benefits to Industry

The rapid expansion of solar energy is transforming the energy sector from a predominantly project-development and installation-oriented industry into a highly integrated ecosystem encompassing polysilicon, ingot and wafer manufacturing, solar cells, modules, balance-of-system components, project development, engineering, procurement and construction (EPC), installation, commissioning, operations and maintenance (O&M), digital monitoring, energy storage, grid integration, asset management and end-of-life management.

As the solar industry expands, the availability of an appropriately skilled workforce becomes a critical factor in determining whether capacity expansion can be translated into reliable manufacturing output, high-quality projects, improved asset performance, domestic value creation and sustainable employment.

Systemic skill deficiencies have caused project delays, balance-of-system (BOS) failures, catastrophic safety hazards, underperforming Plant Load Factors (PLF), and premature asset degradation.Addressing this skill gap transforms the solar sector from a debt-leveraged, import-dependent installation industry into a mature, technologically autonomous, and economically durable industrial ecosystem.

The solar industrial structure consists of developers, Engineering, Procurement, and Construction (EPC) contractors, Original Equipment Manufacturers (OEMs), independent testing agencies, balance-of-system suppliers, and third-party O&M providers.For these entities, systematic workforce development shifts operations away from reactive, crisis-driven field fixes and toward structured, high-precision engineering.

IRENA's analysis of renewable energy value creation highlights the importance of workforce capabilities across the solar PV value chain, including manufacturing, procurement, project development, construction, installation, operations and maintenance.These activities require diverse technical, operational and managerial competencies, reinforcing the need for targeted skill development, industry-aligned training and workforce planning throughout the solar project lifecycle.

Table 29: Skill Gap Reduction and Potential Industrial Impact

Skill Area	Skill Gap Impact	Potential Industry Benefit
Process engineering	Incorrect process parameters	Higher yield and productivity
Equipment operation	Improper operation	Lower downtime
Equipment maintenance	Delayed fault identification	Higher equipment availability
Quality control	Inadequate defect identification	Lower rejection and rework
Automation	Limited ability to operate automated systems	Higher throughput
Data analytics	Poor interpretation of production data	Faster decision-making
O&M	Limited troubleshooting capability	Higher plant availability
Project management	Weak planning and coordination	Lower schedule delays
Supply-chain management	Poor forecasting and inventory planning	Lower inventory and logistics losses
Safety	Inadequate risk identification	Fewer accidents and disruptions

6.1.1. Capex Optimisation & Yield Preservation

- Design Optimisation via Numerical Modelling: Eliminating layout errors, minimising DC/AC mismatch, and optimising land use through software tools (e.g., PVsyst, Helioscope).[42]
- Mitigation of Performance Ratio (PR) Erosion & SCADA Diagnostics: Systematic monitoring, identifying bypassed diodes, and resolving string-level mismatch.
- Robotic Dry Cleaning & Soiling Management: Sensor-driven cleaning schedules to conserve water and prevent abrasive cell damage in arid climates.

Table 30: Maintenance Approaches and Industry Outcomes

Maintenance approach	Workforce requirement	Industry outcome
Reactive	Basic troubleshooting	Longer downtime
Preventive	Scheduled maintenance	Improved reliability
Condition-based	Monitoring and diagnostics	Earlier fault detection
Predictive	Data analytics and AI	Reduced unplanned downtime
Prescriptive	Advanced analytics and optimization	Data-driven maintenance decisions

6.1.2. Reduction in Defects, Rework and Material Losses

Skill gaps can increase the probability of incorrect machine settings, inadequate process control and delayed defect identification.These issues can result in material wastage, rework, production losses and increased manufacturing costs.Addressing skill gaps through competency-based training can help employees identify the root causes of process deviations and implement corrective and preventive measures.

Quality methodologies such as Statistical Process Control, Failure Mode and Effects Analysis, 8D problem solving, Corrective and Preventive Action and root-cause analysis can be incorporated into training programs for engineers, supervisors and quality workforce.Such capabilities can help organisations move from reactive defect correction to preventive quality management.

For a high-volume solar manufacturing facility, even a small improvement in yield can have significant economic implications because the same improvement is applied across a large production volume. Therefore, workforce capability investment can produce benefits through reduced material losses and improved manufacturing asset utilisation.

6.1.3. Reducing Dependence on External Technical Expertise

Skill shortages can increase the dependence of companies on external consultants, equipment suppliers and specialised contractors for technology implementation, commissioning, troubleshooting and advanced maintenance.Developing domestic technical capabilities can enable companies to undertake a greater share of these activities internally.This can reduce response times, improve institutional knowledge and strengthen long-term operational capability.Building expertise within Indian companies can also support technology localisation and improve the country's ability to manage increasingly complex solar manufacturing and power-generation assets.

[42] https://ppp.worldbank.org/sites/default/files/2022-03/IFC_Solar_Report_Web__08_05.pdf

6.1.4. Improvement in Solar Asset Performance and O&M Efficiency

The long-term financial performance of a solar PV project depends on maintaining high plant availability and energy yield throughout its operating life.O&M activities require workforce capable of identifying equipment faults, analysing performance deviations and implementing corrective actions.Critical equipment includes PV modules, inverters, trackers, transformers, switchgear, cables, monitoring systems and auxiliary systems.

Training in SCADA analysis, thermography, drone-based inspection, IV-curve tracing, string-level monitoring, condition monitoring and performance-ratio analysis can improve the effectiveness of O&M activities.Skilled workforce can identify abnormal operating conditions at an early stage and reduce the duration of equipment downtime.This can improve key performance indicators such as plant availability, performance ratio (PR), mean time to detect faults and mean time to repair (MTTR).

The industry is also moving towards predictive and condition-based maintenance.These approaches require workforce who can analyse historical operating data and identify patterns associated with equipment degradation.Therefore, the future O&M workforce will increasingly require a combination of electrical and mechanical expertise with data-analysis and digital-monitoring capabilities.

6.2. Benefits to Workforce

Addressing skill gaps in the solar energy sector can generate significant benefits for the workforce by improving employability, technical competencies, career progression, occupational mobility and long-term adaptability to technological changes.The rapid expansion of solar PV deployment, domestic manufacturing, distributed generation, energy storage and digital energy systems is transforming the occupational structure of the renewable-energy sector.Bridging the skill gap through structured, standardized vocational training builds formal, accredited career paths, provides demonstrable wage premiums, supports local clean energy entrepreneurship, and underpins a Just Transition for workers shifting out of fossil-fuel-reliant industries

6.2.1. Transition to Formal Employment

Nationally Recognized Certifications: Programs aligned with the National Skills Qualifications Framework (NSQF) turn uncertified helpers into accredited professionals such as Solar PV Installers, Rooftop Solar Engineers, and O&M Specialists.Holding a government-recognized credential verified on the NSDC portal changes a worker's market leverage.

6.2.2. Statutory Social Security Coverage

Getting certified helps workers move into formal payroll systems

- Mandatory enrollment in the Employees' Provident Fund (EPF) with a 12% baseline employer contribution, providing long-term retirement savings.
- Enrollment in the Employees' State Insurance (ESI) program granting workers and their dependents full access to outpatient and hospitalization medical care
- Defined 8-hour working shifts, formal appointment letters, and mandatory personal accidental coverages.

6.2.3. Increased Productivity and Individual Performance

Skill development can improve individual productivity by enabling workers to perform tasks more accurately, efficiently and safely.In manufacturing, trained workforce can reduce process deviations and equipment downtime through appropriate operating and troubleshooting practices.In EPC activities, competent workers improve installation quality and reduce rework.In O&M, skilled technicians can identify faults faster and reduce equipment downtime.

Productivity improvements are particularly important in a capital-intensive industry such as solar energy, where equipment utilisation, project timelines and asset availability directly influence economic performance.Workforce development can therefore create a direct linkage between individual competency and measurable operational indicators such as task completion time, first-time-right performance, downtime and rework.

6.3. Benefits to Renewable Energy Ecosystem

Addressing skill gaps across the renewable-energy sector can strengthen the overall renewable-energy ecosystem by improving the availability, quality and mobility of technical Workforce across manufacturing, project development, engineering, procurement and construction (EPC), operations and maintenance (O&M), grid integration, energy storage, research and development, digital services and end-of-life management.The renewable-energy transition increasingly requires a combination of conventional engineering competencies and emerging capabilities in automation, digitalization, power electronics, energy storage and data analytics.IRENA and ILO emphasize that workforce development, including education, vocational training, reskilling, upskilling and on-the-job learning, is increasingly important for developing the capabilities required by the future energy workforce.

6.3.1. Strengthening the Renewable Energy Value Chain

A skilled workforce can strengthen the complete renewable-energy value chain by improving technical capabilities at each stage, from equipment manufacturing and project development to installation, commissioning, O&M and end-of-life management.Renewable-energy value chains involve highly interconnected activities, and skill deficiencies in one segment can create constraints for other segments.For example, inadequate manufacturing capabilities can affect equipment quality and production capacity, while shortages of qualified EPC workforce can contribute to construction delays and commissioning issues.Similarly, insufficient O&M expertise can adversely affect plant availability and energy yield.

The development of occupation-specific competencies can therefore improve the continuity and efficiency of the value chain.This requires skill mapping across roles such as PV manufacturing technicians, process engineers, quality engineers, electrical design engineers, commissioning engineers, SCADA specialists, BESS technicians, renewable-energy analysts and recycling professionals.IRENA notes that renewable-energy employment spans a broad range of occupations, including materials scientists, technology specialists, electricians, machinists, engineers, construction workers, planners and administrators

6.3.2. Development of Regional Renewable Energy Skill Ecosystems

Renewable-energy projects are geographically distributed, including utility-scale solar parks, wind farms, rooftop systems and decentralized renewable-energy applications.Developing regional technical capabilities can reduce dependence on workforce mobilized from distant locations and improve access to skilled workforce.

Regional training centres can provide localized programs for installation, electrical commissioning, O&M and safety.Such institutions can also work with local industries and project developers to identify region-specific skill requirements.This approach can support local employment while improving the availability of technical services near renewable-energy assets.

6.3.3. Strengthening Research, Innovation and Technology Transfer

A skilled workforce can improve the interaction between research institutions and industry by enabling research outcomes to be translated into commercial applications.Renewable-energy innovation increasingly involves multidisciplinary areas such as semiconductor materials, advanced PV technologies, power electronics, energy storage, digital systems, forecasting and recycling.

Professionals with both research and industrial capabilities can support technology demonstrations, pilot-scale deployment and commercialization.This can reduce the gap between laboratory research and industrial implementation and strengthen the domestic innovation ecosystem.

6.3.4. Supporting Circular Economy and End-of-Life Management

The rapid growth of solar PV and battery deployment will create increasing requirements for end-of-life management.PV modules, batteries, inverters and other electrical equipment require specialized processes for collection, testing, dismantling, material recovery, recycling and safe disposal.

The development of skills in PV module recycling, battery handling, material recovery, environmental management and electrical safety can support the emergence of a circular renewable-energy ecosystem. This can simultaneously create new employment opportunities and improve resource efficiency.



7 Recommendations

The survey findings and quantitative assessments demonstrate that workforce development must progress alongside capacity expansion, automation, and technological advancement across the solar PV value chain.The challenges identified extend beyond the raw availability of workers to include industry readiness, specialized technical expertise, training infrastructure, retention, reliance on imported equipment and software, and limited collaboration with academic institutions.

To systematically address these bottlenecks, a comprehensive, decision-oriented strategy has been formulated.This strategy establishes clear operational frameworks, target execution timelines, indicative financial outlays, and measurable outcome Key Performance Indicators (KPIs) across three key institutional pillars: Industry, Training Institutes & Academic Institutions, and Government & Skill Councils.

7.1.Recommendations for Industry

Solar manufacturers, equipment suppliers, Engineering, Procurement, and Construction (EPC) companies, Independent Power Producers (IPPs), and Operations & Maintenance (O&M) service providers must adopt a structured approach to workforce planning, training, competency development, retention, and inclusion.

7.1.1.Developing Structured Workforce Planning and Recruitment Strategies

Solar industry stakeholders should develop dynamic workforce plans based on production capacity, planned expansion, technology adoption, automation levels, operational requirements, and anticipated employee turnover.Requirements must be assessed separately across the distinct stages of the value chain: module, cell, wafer, ingot, and polysilicon manufacturing, as well as utility-scale solar, rooftop solar, decentralized solar, EPC, and O&M.

Recruitment planning should distinguish between fresh graduates, experienced technicians, supervisors, engineers, and specialized professionals.Because many manufacturers undertake monthly recruitment drives to offset shop-floor turnover, companies should establish an annual recruitment and training calendar.This calendar must link hiring targets directly with the availability of training batches, supervisory capacity, and suitable production-line assignments.Recruitment planning must explicitly account for replacement demand driven by attrition, rather than focusing solely on capacity expansion.

Where technically appropriate, companies should maintain a balanced recruitment pipeline comprising fresh candidates and experienced professionals.Experienced workers stabilize new production lines, support process optimization, and mentor newly recruited workers, while fresh recruits can be developed through structured training and workplace experience.

7.1.2 Introduce Structured Induction, Technical Training and Competency Assessment

Companies should establish clearly defined induction and technical training programs for all new employees, including contractual and off-role workforce.Organizations must move away from brief 2- to 3-day orientations toward a standardized, 12-day modular framework that combines behavioral and workplace orientation with technical instruction, supervised shop-floor training, and rigorous competency assessment before independent deployment.

The duration and depth of training should depend on the complexity and safety requirements of the job role.Short induction programs must not substitute for equipment-specific training, practical assessment, or supervised workplace learning.Before assigning independent responsibilities, companies should formally assess employees on equipment operation, Standard Operating Procedures (SOPs), quality requirements, safety practices, troubleshooting, and their ability to respond to abnormal operating conditions.Training records and competency matrices should be maintained to support deployment decisions and identify additional training needs.

Employers must also address early-career turnover-where a substantial proportion of new recruits leave within the first four months-by strengthening onboarding support, mentoring, and early-career orientation.

7.1.3. Establish Specialized Training Facilities for Solar Manufacturing

Manufacturers should establish or strengthen dedicated in-plant training centres for ITI, diploma, and engineering workforce to provide practical exposure before employees undertake independent shop-floor responsibilities.

Priority technical training areas include:

- Module Manufacturing: Automated stringer and printing operations, lamination, automated production, Electroluminescence (EL) image analysis, Automated Optical Inspection (AOI), quality assurance, and machine troubleshooting.
- Cell Manufacturing: Semiconductor processing, TOPCon and Heterojunction (HJT) cell architectures, cleanroom operations, diffusion, deposition, chemical handling, cell characterization, and process control.
- Ingot & Wafer Manufacturing: Czochralski (CZ) crystal growth, furnace operation, thermal management, diamond wire-saw control, precision metrology, material properties, and defect reduction.
- Equipment & Automation: Programmable Logic Controllers (PLCs), robotics, industrial control systems, equipment calibration, machine diagnostics, and preventive maintenance.
- Quality & Manufacturing Systems: Process monitoring, defect classification, yield improvement, traceability, and manufacturing data analysis.

Companies should develop qualified internal trainers from experienced employees and equipment specialists.Where advanced machinery is cost-prohibitive to duplicate in dedicated training facilities, companies should utilize simulation systems, retired or surplus equipment, demonstration rigs, and supervised access to operational production lines.

7.1.4. Develop Transferable Skills and Support Cross-Sector Recruitment

Industry should recognize that relevant technical capabilities exist in adjacent sectors such as automotive manufacturing, steel, industrial automation, and consumer electronics.Recruitment strategies should actively identify candidates whose existing competencies can be adapted to solar manufacturing requirements.

Workforce with experience in industrial automation, robotics, and automotive assembly lines are well-suited for module manufacturing operations.Similarly, candidates from metallurgical, mechanical, electrical, chemical, and instrumentation engineering backgrounds should be targeted for ingot, wafer, and cell manufacturing functions.Cross-sector recruitment must be supported by bridging programs covering solar-specific processes, equipment, quality standards, and safety procedures.

Companies should also strengthen campus recruitment, internships, and graduate trainee programs across engineering disciplines.AI-enabled recruitment screening may be used to support candidate shortlisting, but final assessments should retain role-specific evaluations, transparent selection criteria, and human review.

7.1.5. Strengthen Advanced Technical Skills Across Manufacturing Value Chain

Manufacturers should establish technical training pathways tailored to the complexity of each manufacturing stage.While module assembly requires an emphasis on automated equipment operation, stringing, lamination, EL inspection, AOI, defect detection, and machine troubleshooting, cell manufacturing demands deeper process knowledge in cleanroom protocols, diffusion, deposition, passivation, metallization, chemical safety, and yield improvement.

Ingot and wafer manufacturing require specialized training in crystal growth physics, high-temperature furnace operation, thermal management, impurity control, diamond wire slicing, wafer metrology, and process optimization.As domestic polysilicon capabilities emerge, specialized training must be established in chemical engineering, purification processes, reactor operation, hazardous gas handling, contamination control, and process safety.

Companies must also build advanced internal expertise in equipment commissioning, line stabilization, root-cause analysis (RCA), and applied R&D to reduce reliance on external technical specialists.

7.1.6. Reduce Dependence on Imported Equipment and Proprietary Software

Dependence on imported machinery, proprietary equipment software, external technical support, and supplier-led upgrades severely constrains operational independence.Industry must build structured knowledge-transfer arrangements directly into equipment procurement contracts.Contracts for machinery procurement and commissioning should explicitly mandate the technical training of Indian engineers, full technical documentation, maintenance SOPs, software training, and local troubleshooting capabilities.

Manufacturers should collaborate with domestic machinery developers, engineering institutions, and software companies to build indigenous automation solutions, industrial software, machine-vision tools, and equipment control systems.Furthermore, companies should train their technical workforce in PLCs, SCADA, Manufacturing Execution Systems (MES), robotics, machine vision, and predictive maintenance while establishing appropriate safeguards for operational data, software access, and cybersecurity.

7.1.7. Strengthen Graduate Trainee and Experienced Employee Development

Manufacturers and renewable energy developers should establish structured career pathways for Graduate Engineer Trainees (GETs), experienced technicians, and specialized professionals.GET programs should combine classroom instruction, equipment demonstrations, supervised assignments, interdepartmental rotations, and formal competency assessments.

Companies should prioritize internal promotions to fill technical vacancies whenever qualified employees are available.Clear criteria for progression into senior engineering, deputy management, and management positions should be communicated transparently.Continuing professional development, leadership training, and technical specialization opportunities should be provided to build a strong pipeline of internal talent for senior technical and managerial roles.

7.1.8. Improve Employee Retention, Workforce Stability and Local Employment

Employee turnover disrupts production, elevates recruitment costs, and leads to repeated expenditure on basic training.Companies should monitor attrition separately for fresh recruits, experienced technicians, engineers, supervisors, contractual workers, and specific operational departments to design targeted retention measures.

Effective retention strategies include:

- Structured onboarding, mentoring, and early-career support.
- Transparent technical career pathways and internal promotion policies.

- Skill-based pay incentives, recognition programs, and performance bonuses.
- Provision of accommodation, transport, subsidized meals, and site allowances.
- Facilitation of transfers to operational locations closer to workers' home regions where feasible.

Manufacturers operating in remote locations should align workforce planning with local demographic constraints, candidate availability, transport, and housing infrastructure.Where operations rely heavily on contractual or third-party labor, employers must ensure that these workers receive identical job-specific technical training, safety instruction, and competency assessments as permanent staff.

7.1.9. Expand Industry-Academia Collaboration and Applied Research

Industry must establish formal partnerships with ITIs, polytechnics, engineering colleges, and research universities.Industry participation should cover curriculum revision, practical demonstrations, internships, apprenticeships, faculty attachments, equipment sharing, applied research, and campus placement.Companies should regularly depute technical experts to deliver guest lectures on contemporary industrial practices.

Where feasible, companies should donate surplus or decommissioned equipment, sample solar cells, modules, and testing instruments to educational institutions, backed by proper safety assessments and installation support.Industry should also define specific research problems for M.Tech.and Ph.D.students in areas such as process optimization, line stabilization, equipment reliability, material characterization, automated defect detection, and indigenous tool development.Standardized Non-Disclosure Agreement (NDA) and Intellectual Property (IP) frameworks must be adopted to protect proprietary data while allowing students to satisfy academic dissertation requirements.

To incentivize corporate participation in hands-on talent development, industry may consider co-funding apprenticeship stipends matching National Apprenticeship Promotion Scheme (NAPS) norms (₹1,500 to ₹4,500 per month per apprentice).Across the 2026-2030 planning horizon, this initiative will require an indicative financial outlay of ₹216 crores up to 2030, funded through a combination of NAPS subsidies and corporate allocations.This investment aims to induct over 15,000 active apprentices into manufacturing and EPC roles, with a target 1-year post-apprenticeship retention rate of over 75% within hiring organizations.

7.1.10.Strengthen Workforce Development for EPC, IPPs, O&M and Rooftop Solar

EPC contractors, IPPs, and O&M service providers should institute structured technical training covering project design, procurement, quality assurance, site execution, electrical installation, grid commissioning, and long-term asset management.

Design teams must strengthen competencies in yield modeling, electrical layout design, grid connectivity, Battery Energy Storage System (BESS) integration, and performance optimization.Field construction crews require task-specific instruction in cable termination, torque calibration, electrical testing, high-voltage substation installation, working at height, and emergency response.

O&M training must emphasize preventive and predictive maintenance, SCADA analytics, inverter and transformer troubleshooting, thermography, data interpretation, and robotic cleaning operations. Technicians should be trained to validate AI-generated alerts and perform root-cause analysis rather than relying solely on automated outputs.For rooftop solar and agricultural installations, manufacturers and distributors should conduct field-engineer training through established service networks.

7.1.11.Improve Workforce Inclusion and Occupational Safety

Industry should create expanded opportunities for women across manufacturing, engineering, project execution, O&M, and supervisory roles.Increasing female participation at remote solar project sites requires combining recruitment targets with safe accommodation, dedicated transport, supportive workplace policies, and clear career progression.

Awareness campaigns highlighting technical career pathways in solar energy should be conducted in Tier-2 and Tier-3 cities through industry visits, career sessions, and internships.

Workplace safety must remain a mandatory prerequisite for deployment.Companies must ensure that all workers receive task-specific instruction in electrical isolation, Lockout/Tagout (LOTO) protocols, hazardous gas/chemical handling, high-voltage systems, working at height, industrial machinery, and emergency response prior to undertaking site duties.

7.2. Recommendation for Training Institutes and Academics Instructions

Training providers and academic institutions must modernize their educational frameworks to provide a balanced combination of foundational engineering principles, specialized technical instruction, practical laboratory learning, industry exposure, and competency-based assessment.

7.2.1. Review and Update Curricula in Consultation with Industry

Engineering and vocational curricula should undergo periodic review with active industry representation. Institutions should establish interim curriculum update mechanisms to integrate emerging technologies between formal syllabus revision cycles.

Priority subjects to embed across courses include:

- Advanced cell architectures (TOPCon, HJT, back-contact).
- Automated module production, PLCs, SCADA, and robotics.
- AI and ML applications in defect detection and generation forecasting.
- PVsyst modelling, 3D shading analysis, and high-voltage electrical design.
- Solar-plus-BESS integration, smart inverters, and grid compliance codes.
- Predictive O&M, radiometric thermography, and PV recycling processes.

Curricula must be differentiated according to occupational streams-such as cell manufacturing, module assembly, upstream silicon processing, solar EPC, rooftop solar, and utility O&M-rather than offering a single, generic solar module.

7.2.2. Establish Advanced Laboratories and Industry-Linked Training Centres

Academic institutions must develop practical laboratories equipped with industry-relevant solar hardware and software.Core laboratory facilities should include module assembly demonstration setups, EL testing units, AOI tools, cell characterization benches, solar simulators, grid-tie inverters, BESS demonstration units, PLCs, SCADA testbenches, and industrial automation trainers.

To bridge the critical gap in high-tech manufacturing skilling, a dedicated program must be executed to establish four Regional Centres of Excellence (CoEs) and advanced cleanroom/simulation laboratories in key solar hubs across Gujarat, Telangana, Tamil Nadu, Rajasthan and later in all other states where many solar manufacturing and Power Generation projects may be locatedin future.Executed over a 1 to 4 year timeline through a consortium involving IITs/NITs, the Ministry of Education, and State Governments, this initiative carries an indicative financial outlay of ₹120 crores (₹30 crores per CoE). Key outcome KPIs for these CoEs include the annual publication of joint industry-academia research papers and achieving high placement rates for postgraduate trainees within domestic cell, wafer, and ingot manufacturing enterprises.

7.2.3. Strengthen Practical Training and Industry Exposure

Academic programs should incorporate mandatory, structured opportunities for students to apply theoretical learning to real industrial environments.B.Tech.curricula should mandate 2-month internships during the third or fourth year, while M.Tech.programs should incorporate 6-month to 1-year industrial research placements.

Industry-supported internships must include structured learning plans, joint academic-industry supervision, practical assignments, and mandatory stipends.Technical institutions should establish formal agreements with solar companies to ensure internship availability.Students must gain practical exposure to operational manufacturing lines, electrical test benches, quality control systems, site safety procedures, and specialized industry software.

7.2.4. Strengthen Faculty Development and Industry Participation in Teaching

Faculty members require regular industrial attachments, technical workshops, equipment demonstrations, and professional development to keep pace with evolving industry technologies.

Institutions should regularly invite industry engineers, plant managers, and technical specialists to conduct guest lectures, lead laboratory workshops, and assist in student mentoring.Faculty development programs should focus on automation, advanced manufacturing machinery, digital diagnostics, quality control systems, and industrial safety standards, ensuring that instructors can incorporate contemporary industry examples into their teaching.

7.2.5. Promote Industry-Supported Research and Postgraduate Education

Universities should align M.Tech.and Ph.D.research projects with practical technical challenges identified by solar manufacturers, EPC contractors, and plant operators.

Focus areas for postgraduate research include manufacturing yield optimization, ingot/wafer crystal quality, thin-film passivation, equipment reliability, automated visual defect detection, industrial control software, solar generation forecasting, BESS integration, and PV end-of-life recycling.Industry partners should supply research problem statements, co-supervision, and access to testing facilities or operational datasets.Universities and corporate partners should execute pre-agreed research contracts defining data confidentiality, publication review timelines, and IP rights.

7.2.6. Develop Competency-Based Training for ITI and Diploma Students

ITIs and polytechnics must upgrade their practical training in machine operation, industrial automation, mechanical/electrical maintenance, quality inspection, and solar installation.

Specialized trade modules should be introduced for module assembly, cell production line operations, wafer processing, equipment maintenance, and rooftop solar installation.Learning should emphasize practical exercises, machine operation, fault simulation, and formal competency testing.Where institutions lack advanced internal equipment, practical sessions should be conducted through regional shared training centres or structured workplace attachments.

7.2.7. Expand Career Guidance and Employment Linkages

Academic institutions should expand career guidance and outreach programs to raise awareness of solar sector opportunities among students, particularly in Tier-2 and Tier-3 cities.

Career guidance should outline educational requirements, job roles, and career progression across manufacturing, engineering, grid integration, O&M, rooftop solar, energy storage, and R&D.Institutions should organize industry visits, guest lectures, technical demonstrations, and alumni interactions to inform prospective candidates.Placement cells should build formal partnerships with solar employers for campus recruitment, apprenticeships, and graduate trainee intake.

7.2.8. Monitor Training Outcomes and Industry Readiness

Institutions should systematically track training outcomes using indicators such as program completion rates, practical assessment pass rates, industry certification, internship placement, graduate employment rates, and employer feedback.

Training providers must evaluate whether graduates demonstrate the practical skills required to perform workplace tasks and operate equipment safely.Feedback from employers and alumni should directly inform syllabus updates, laboratory investments, and faculty development planning.Program effectiveness must be judged on demonstrated graduate competency and job placement rather than student enrolment numbers alone.

7.3. Recommendation for Government and Skill Councils

Government agencies, skill development bodies, and regulatory authorities must establish the policy, regulatory, financial, and institutional framework required to support workforce planning, infrastructure development, standardized certification, and cross-sector coordination.

7.3.1. Establish a National and State-Level Solar Workforce Planning Framework

A coordinated national workforce planning framework must be established to continuously project skill requirements across solar manufacturing, EPC, utility IPPs, O&M, rooftop solar, PM-KUSUM, BESS, and recycling.

Workforce demand projections must distinguish between manufacturing value chain nodes, occupational levels, temporary construction employment, and long-term operational jobs, while accounting for production automation, planned capacity expansion, attrition, and replacement demand.State-level workforce assessments should be conducted to map skill requirements in major manufacturing hubs and high-deployment solar regions.

The Ministry of New and Renewable Energy (MNRE), Ministry of Skill Development and Entrepreneurship (MSDE), State Skill Development Missions (SSDMs), industry associations, and the Skill Council for Green Jobs (SCGJ) should periodically share aggregated workforce data to align training supply with industry demand.

7.3.2. Upgrade Government-Supported Training Infrastructure

Government agencies may invest in upgrading practical training infrastructure across selected public ITIs, polytechnics, and specialized skill centres located near major industrial clusters and solar parks.

To execute this, a national initiative must be launched to upgrade training infrastructure, solar simulators, lab testbenches, and mock-up rooftops across 100 strategic ITIs and polytechnics.Managed by MSDE, the Directorate General of Training (DGT), SSDMs, and SCGJ, this initiative carries an execution timeline of 6 to 36 months with an indicative financial outlay of ₹75 crores (₹75 Lakhs per centre).Key outcome KPIs include:

- The number of upgraded ITIs fully operational.
- Annual student enrollment across specialized solar trades.
- Student pass percentages in practical NCVET/SCGJ competency evaluations.

Government funding should cover laboratory equipment, trainer development, maintenance grants, and practical assessment systems.

7.3.3. Leverage Existing Training Networks and Programmes

Government agencies should map existing training networks-including the Surya Mitra program and its affiliated network of approximately 490 training centres across India-to evaluate their operational capacity, course offerings, and infrastructure readiness.

Existing training networks should be upgraded to incorporate instruction in advanced cell manufacturing, module automation, digital O&M, SCADA, equipment maintenance, and BESS systems.Training programs should be stratified by qualification level: basic solar installer courses should continue serving distributed installation needs, while advanced technician and engineering modules should be introduced for automated manufacturing and utility-scale operations.

7.3.4. Strengthen Occupational Standards and Certification

SCGJ, the National Council for Vocational Education and Training (NCVET), and relevant technical bodies must regularly review National Occupational Standards (NOS) and Qualification Packs (QPs) in consultation with industry.

Updated QPs must cover automated stringing, cleanroom cell processing, CZ crystal growth, wafer slicing, industrial automation, PLC/SCADA maintenance, high-voltage substation operations, and predictive O&M.Certification must evaluate practical technical competency, safety protocols, and task execution.Distinct certification pathways should be established for entry-level operators, experienced technicians, supervisors, engineers, and safety specialists.

In addition, a specialized Regulatory Safety and High-Voltage Certification Framework shall be established by the Central Electricity Authority (CEA), State Electrical Inspectorates, and SCGJ between 3 and 18 months.Supported by an indicative financial outlay of ₹8 crores for curriculum design, safety manual drafting, digital examination portals, and inspector training, this initiative targets two critical outcome KPIs:

- Achieving zero fatal electrical accidents across utility-scale solar construction sites.
- Ensuring 100% compliance audit closures for Chief Electrical Inspector to Government (CEIG) high-voltage substation grid-tie approvals.

7.3.5. Expand Recognition of Prior Learning

Recognition of Prior Learning (RPL) programs must be expanded to assess and formally certify existing workers who have acquired skills through informal workplace experience.

RPL frameworks should combine practical skills evaluation, safety testing, and targeted gap training where deficiencies are identified.Uncertified workers who complete the assessment should receive formal NSQF-aligned credentials.RPL should be rolled out extensively under distributed generation schemes such as PM Surya Ghar.

Specifically, a nationwide Modular Upskilling and RPL Certification Campaign must be implemented by SCGJ, the National Institute of Solar Energy (NISE), and industry partners over Months 0 to 24.With an indicative financial outlay of ₹45 crores (based on standard skilling benchmarks of a ₹3,000 training fee plus a ₹3,500 candidate stipend per worker for 70,000 workers), the program's success will be measured by:

- The number of uncertified field technicians formally assessed and certified (target: 1,00,000 workers).
- The percentage of certified workers transitioning into formal payroll systems with statutory Employees' Provident Fund (EPF) and Employees' State Insurance (ESI) coverage.

7.3.6. Support Industry-Academia Partnerships, Internships and Research

Government bodies should establish policy frameworks and funding incentives to encourage industry-academia collaboration.Grants and tax incentives should support industry-sponsored laboratories, faculty attachments, apprenticeships, joint R&D projects, and Centres of Excellence.

Government guidelines should provide standard agreement templates covering NDA terms, data sharing, IP ownership, publication rights, and dissertation timelines.These templates will protect commercially sensitive industrial information while allowing postgraduate students to fulfil academic requirements without procedural delays.

7.3.7.Promote Indigenous Equipment, Software and Technology Development

Government policy should actively promote domestic technological self-reliance across manufacturing equipment, industrial automation, and software systems.Support should target precision machinery, crystal growth furnaces, diamond wire saws, PECVD equipment, automated stringers, robotics, PLCs, SCADA software, and machine-vision inspection systems.

Skill development initiatives must be integrated into broader industrial policies-such as the Production Linked Incentive (PLI) scheme-to ensure that capital investments in manufacturing capacity are matched by investments in local engineering talent.Collaboration among machinery suppliers, research institutions, and solar manufacturers should be funded to support technology localization and build a competent domestic technical workforce.

7.3.8.Promote Apprenticeships and Structured Workplace Training

Government agencies, MSDE, and SCGJ should partner with solar enterprises to expand apprenticeships under the National Apprenticeship Promotion Scheme (NAPS).Standardized apprenticeship frameworks should define practical learning outcomes, supervisory requirements, workplace safety, and competency testing across manufacturing, EPC, and O&M operations.

Policy mechanisms should encourage employers to recruit and train fresh graduates through structured GET and technician training programs.Financial support and skilling grants should be linked directly to training quality, practical learning facilities, and verified competency outcomes rather than enrolment headcount.

7.3.9.Strengthen Career Awareness and Women’s Participation

Government agencies, educational authorities, and skill councils should run public career awareness campaigns highlighting employment pathways in the solar sector, targeting schools, ITIs, polytechnics, and colleges in Tier-2 and Tier-3 cities.

Dedicated initiatives must be launched to increase female participation in solar manufacturing, project engineering, site operations, and managerial roles.Government support should provide training stipends for female candidates, promote safe workplace infrastructure at remote project sites, and encourage equal-opportunity hiring practices across government-assisted clean energy projects.

7.3.10.Facilitate Advanced Training and International Knowledge Exchange

Where domestic expertise or specialized training infrastructure is currently limited-particularly in upstream silicon refining, CZ crystal pulling, cleanroom cell deposition, and advanced power electronics-government agencies should facilitate international training partnerships and knowledge exchange.

Technical exchange programs, trainer-development initiatives, and international institutional partnerships should be established with recognized global clean-energy training bodies.Every international training initiative must incorporate a mandatory “train-the-trainer” component to ensure that returning specialists can cascade technical expertise to local institutions, build domestic training capacity, and establish self-sustaining local programs.

7.3.11.Develop a Monitoring Framework for Training Quality and Outcomes

Government authorities and SCGJ must implement a comprehensive monitoring and quality assurance framework to evaluate publicly funded solar skilling programs.

Key performance indicators within this monitoring framework must track:

- Practical training completion rates.
- Competency assessment pass rates.
- Industry certification issuance.
- Apprenticeship completion and conversion rates.
- Post-training employment rates and wage levels.
- Employer satisfaction metrics.

Training centres should undergo periodic quality audits evaluating equipment adequacy, trainer credentials, curriculum relevance, and industry placement linkages.Audit findings should directly determine program continuation, funding allocations, and centre accreditations, ensuring that public skilling expenditure delivers verifiable technical capability and job readiness.

Across the four-year implementation window (2026-2030), the aggregate total estimated programme outlay across all government, industry, and academic action areas stands at ₹464 crores.Executing this comprehensive roadmap will enable the sector to formally certify over 1.7 lakh solar professionals, reduce initial equipment breakdown rates by 35%, and preserve an estimated ₹1,600 crores in asset yields and avoided rework across India’s clean energy infrastructure over the decade.



8 Conclusion

India's ambitious national energy transition, anchored by the Panchamrit commitment to achieve 500 GW of non-fossil fuel capacity by 2030, relies fundamentally on the rapid expansion of solar photovoltaic (PV) technology.Backed by large-scale sovereign interventions such as the PM Surya Ghar: Muft Bijli Yojana and the PM-KUSUM initiative, India's cumulative solar capacity reached 171.05 GW by September 2026, driving an unprecedented surge in demand for skilled human capital across the entire value chain.

As demonstrated through empirical modelling, India's total solar workforce across manufacturing and power generation is projected to expand by 113%, growing from a 2026 baseline of approximately 1.80 lakh personnel to nearly 3.70 lakh personnel by March 2030.This expansion is characterized by a disproportionate 149% surge in white-collar professional demand, propelled by backward integration into technologically complex upstream nodes-including polysilicon refining, Czochralski ingot pulling, and cleanroom cell microfabrication.

However, the study reveals critical structural vulnerabilities: traditional vocational and academic pathways have failed to keep pace with rapid technological shifts toward n-type TOPCon/HJT architectures, AI/ML-driven predictive O&M, and high-voltage grid integration.Persistent competency gaps, high employee attrition rates (12% to 30%), and limited practical laboratory infrastructure threaten project execution, asset yields, and workplace safety.

Addressing these challenges requires a decisive, coordinated transition from reactive hiring to structured, institutionally backed workforce development.By implementing the strategic roadmap outlined in this assessment-encompassing industry-led induction and retention frameworks, curriculum modernization across ITIs and engineering colleges, and government-backed initiatives such as ITI infrastructure upgrades, Recognition of Prior Learning (RPL), and specialized Centres of Excellence-India can systematically close its skill deficits in the Solar sector.

Supported by a targeted national program outlay of approximately ₹460 crores spanning the 2026-2030 planning horizon, this collaborative strategy will formalize over 1.7 lakh green jobs, reduce initial plant breakdown rates by about one-third, and preserve an estimated ₹1,600 crores in asset yields and avoided rework.Ultimately, targeted investment in human capital is the definitive prerequisite to securing India's industrial self-reliance, ensuring long-term asset reliability, and cementing its global leadership in the sustainable clean energy transition.

Annexure I

Solar Cell Manufacturing Job Roles and Indicative NSQF Levels

Department	Job Role	Indicative NSQF Level	Educational Qualification	Experience Required	Key Responsibilities
Module Production	Senior Engineer Module Production	6	B.E./B.Tech. in Electrical/ Electronics/ Mechanical	3-5 years	Manage cell placement, stringing and front-end module production; monitor output, quality and process parameters; coordinate with QA and maintenance.
	Module Production Engineer	6	B.Tech./ Diploma in Engineering	2-5 years	Monitor production targets, yield, workforce, machine availability and process performance.
	Production Supervisor / Line Lead	5	Diploma/ B.E./B.Tech.	3-6 years	Manage shift operations, workforce allocation, SOP compliance, safety and daily production reporting.
	Stringer Operator	4	ITI/Diploma preferred	0-3 years	Operate stringer equipment, monitor cell stringing, conduct routine checks and address minor machine issues.
	Assistant Manager Module Production	7	B.Tech./ Diploma	6-10 years	Manage production targets, workforce, yield, efficiency, downtime and scrap; coordinate with quality, maintenance, process and SCM.
	Senior Manager/ DGM - Module Production	7	B.Tech./ Diploma	12-18 years	Lead end-to-end module manufacturing, productivity, cost, quality, delivery, workforce and continuous improvement.
	Senior Manager Module Production	7	B.Tech./ Diploma	12-15 years	Lead module production, optimize throughput, reduce rework/defect and material wastage, drive CAPA and continuous improvement.

Department	Job Role	Indicative NSQF Level	Educational Qualification	Experience Required	Key Responsibilities
Module Process	Process Engineer Module	6	B.Tech.in Electrical/ Mechanical/ Electronics/ Production	2-6 years	Develop and optimize module processes, establish process parameters, troubleshoot defects and improve yield and throughput.
	Senior Process Engineer	6	B.E./B.Tech./ MTech.	4-8 years	Conduct RCA, FMEA, DOE, SPC and process trials; optimize CT, yield and process capability.
Module Quality	IQC Engineer Module	5	B.Tech./ Diploma	1-5 years	Inspect incoming cells, glass, EVA/ POE, back sheets, ribbons, junction boxes and other materials; monitor supplier quality.
	IPQC / Module Quality Engineer	6	B.E./B.Tech.	2-6 years	Monitor stringing, lay-up, lamination, framing and junction-box processes; analyze defects and implement CAPA.
	Customer Quality Module Quality Engineer	6	B.E./B.Tech.	3-7 years	Investigate customer complaints, conduct 8D/RCA, coordinate corrective actions and support field-failure analysis.

Department	Job Role	Indicative NSQF Level	Educational Qualification	Experience Required	Key Responsibilities
Module Maintenance	Mechanical Maintenance Engineer Module	6	B.Tech. /Diploma Mechanical	2-6 years	Maintain laminators, framing systems, conveyors and pneumatic/ hydraulic equipment; execute preventive and breakdown maintenance.
	Senior Engineer Module Maintenance	6	B.E./B.Tech. Electrical/ Electronics/ Mechanical	2-5 years	Maintain and stabilize module-line equipment, particularly stringing machines; improve equipment reliability and manage spares.
	Assistant Manager Module Maintenance	7	B.E./B.Tech.	6-10 years	Lead maintenance teams, preventive maintenance, breakdown analysis, spare management and equipment Uptime improvement.
Module Engineering & Technology	Module R&D Engineer	6	MTech./B.E./B. Tech.	2-7 years	Develop new module designs, materials, encapsulation systems and interconnection configurations; conduct prototype validation.
Materials & Supply Chain	Material Management Engineer/ Executive	5	Diploma/ B.E./B.Tech./ Supply Chain	1-5 years	Manage material availability, inventory, traceability, warehouse coordination and production requirements.
	Module Procurement Engineer	6	B.E./B.Tech./ Diploma	1-5 years	Source cells, glass, encapsulants, back sheets, ribbons, junction boxes and other components; manage suppliers and specifications.
PPC & Operations Planning	PPC Engineer - Module	6	B.E./B.Tech./ Diploma	1-5 years	Prepare production schedules, monitor capacity, coordinate material availability and track production plans.

Department	Job Role	Indicative NSQF Level	Educational Qualification	Experience Required	Key Responsibilities
HSE & Sustainability	HSE Engineer -Module Manufacturing	6	B.E./B.Tech./ Diploma + HSE qualification	1-5 years	Conduct risk assessments, safety inspections, LOTO compliance, PPE monitoring and safety training.
Utilities & Plant Infrastructure	Electrical Utilities Engineer	6	B.E./B.Tech. Electrical	2-6 years	Manage power distribution, electrical infrastructure, backup systems and plant electrical utilities.
	Utility / HVAC Engineer	6	B.E./B.Tech. Mechanical	2-6 years	Manage HVAC, compressed air, cooling systems, water systems and other plant utilities.

Annexure II

Stakeholder Outreach Organisations were selected to represent the major segments of the solar energy value chain. Together they account for about 80 per cent of the market in India.

Table 31: Stakeholder Outreach

Stakeholder category	Approached	Responded
Solar Manufacturing	18	15
Solar IPP	9	7
Solar EPC	10	8
Solar O&M	8	5
Technical consultancy and training institutions	4	3
Academics	3	2
Total Stockholders	52	40

In addition to organisation-level outreach, survey questionnaires were circulated to about 215 individuals in the solar sector.

The detailed sample survey form used during the survey is attached in annexture III

Annexure III – Survey Form

Skill Gap Studies for Solar PV and Wind Sectors in India
Survey Form- Solar PV Manufacturing

SECTION A: Interview/Interviewer Profile

Organization Name:
Coordinator Name:
Designation: E Mail ID:
Mobile Number:

Sub coordinator Details:

Sl. No.	Name of Sub Coordinator	Designa-tion	Email ID	Mobile no	Data Shared
1					
2					

CII Coordinator Name: Mail ID:

Designation: Mobile number:

SECTION B: Organization Profile (Select whichever is applicable)

Sl. No.	Particulars	Details
1	Type of Activity	☐ Polysilicon Manufacturing ☐ Ingot Manufacturing ☐ Wafer Manufacturing ☐ Cell Manufacturing ☐ Module Manufacturing ☐ Others (Please Specify)
2	Main Solar Products	☐ Polysilicon ☐ Ingots ☐ Wafers ☐ Cells ☐ Modules ☐ Front Sheet ☐ Back Sheets ☐Inverter
3	Address of Corporate Office	
4	Plant Locations	

SECTION C: Solar PV (Manufacturing)

Operations Data (For Polysilicon Solar Ingot/ Wafer/ Cell/ Module/ Inverter/ Module Mounting Structures)

Sl. No.	Particulars	As on 31st July 2026
1	Annual manufacturing capacity Polysilicon (Metric Tonnes) Ingots and Wafers (Metric Tonnes) Cells (MWp) Modules (MWp) Inverters (Rated MW) Others (please specify) _____	
2	**Material supplied / deployed at sites till March 2026** (MW **or any other applicable unit**) Polysilicon (Metric Tonnes) Ingots and Wafers (Metric Tonnes) Cells (MWp) Modules (MWp) Inverters (Rated MW) Mounting Structures (Metric Tonnes) Others (please specify) _____	
3	Total **number** of manufacturing/ assembly plants in India Polysilicon Ingots and Wafers Cells Modules Inverters Mounting Structures Others (please specify) _____	
4	Total **number** of employees Polysilicon Ingots and Wafers Cells Modules Inverters Mounting Structures Others (please specify) _____	

Section-D: Workforce Details & Skill Gap Assessment

Sl. No.	Job Role	Existing numbers	Required numbers by 2030	Required Qualification & Experience	Skills Required	Skill Gap/ Upskilling required*
1						
2						

*For more details refer to predefined skill sets required

New Roles Expected (Next Five Years)

Designation / Job roles	Qualifications & Experience	Skills Required	Numbers

SECTION E: Training & Upskilling Needs

Particulars	Details
Annual Training Budget (INR in Crore)	
No. of Employees Trained Annually	
Preferred Training Mode	☐ Classroom ☐ Online ☐ Onsite
Training Staff	☐ In-house ☐ Third party ☐ Both
Key Areas for Training	
Certification Required	☐ Yes ☐ No

SECTION F: Key Challenges Regarding Manpower

☐ Lack of skilled manpower

☐ High attrition

☐ Shortcomings in certain skillsets (Specify)

☐ Lack of availability of courses for bridging skill gaps

☐ Lack of training staff

☐ Others: _____

SECTION G: Recommendations from Industry

SECTION H: Surveyor Notes

Skill Gap Studies for Solar PV and Wind Sectors in India

Survey Form-Solar PV Project Developer

SECTION A: Interview/Interviewer Profile

Organization Name:
Coordinator Name:
Designation: E Mail ID:
Mobile Number:

Sub coordinator Details:

Sl. No.	Name of Sub Coordinator	Designation	Email ID	Mobile No	Data Shared
1					
2					

CII Coordinator: E Mail ID:

Designation: Mobile number:

Section B: Solar PV Project Development

Operations Data

Sl. No.	Particulars	As on 31st July 2026
1	Cumulative Capacity of Solar PV System Deployed (MW)	
2	Number of Plants Installed in India	
3	Total number of employees Number of employees on payroll Number of contract employees	

Workforce Details & Skill Gap Assessment

Sl. No.	Job Role	Existing numbers	Required numbers by 2030	Required Qualification & Experience	Skills Required	Skill Gap/ Upskilling required*
1						

Training and Skilling

Srno	Job Role	Skill Required	Gap in Skill	Remarks (for upskilling)

*For more details refer to predefined skill sets required reference sheet

New Roles Expected in next 5 Years

Designation / Job roles	Qualifications & Experience	Skills Required	Numbers

SECTION C: Key Challenges Regarding Manpower

☐ Lack of skilled manpower

☐ High attrition

☐ Shortcomings in certain skillsets (Specify)

☐ Lack of availability of courses for bridging skill gaps

☐ Lack of Training Staff

☐ Others: _____

SECTION D: Recommendations from Industry

Skill Gap Studies for Solar PV and Wind Sectors in India

Survey Form - Operation & Maintenance- Solar PV

SECTION A: Interview/ Interviewer Profile

Organization Name:
Coordinator Name:
Designation: E Mail ID:
Mobile Number:

Sub coordinator Details:

Sl. No.	Name of Sub Coordinator	Designation	Email ID	Mobile no	Data Shared
1					
2					

CII Coordinator Name: Mail ID:

Designation: Mobile number:

Section B: Operation & Maintenance

Operations Data

Sl. No.	Particulars	As on 31st July 2026
1	Cumulative Capacity of Solar PV System Maintained in India (MW)	☐ Rooftop _____ ☐ Ground Mounted _____ ☐ Other (pl specify) _____
2	Number of Plants for which O&M Services are Provided	☐ Rooftop _____ ☐ Ground Mounted _____ ☐ Other (pl specify) _____
3	Total number of employees on payroll	☐ Rooftop _____ ☐ Ground Mounted _____ ☐ Other (pl specify) _____
4	Total number of employees on contract	☐ Rooftop _____ ☐ Ground Mounted _____ ☐ Other (pl specify) _____

Section-C: Workforce Details & Skill Gap Assessment

Sl. No.	Job Role	Existing numbers	Required numbers by 2030	Required Qualification & Experience	Skills Required	Skill Gap/ Upskill-ing required*
1						
2						
3						

***For more details refer to predefined skill sets required**

New Roles Expected

Designation / Job roles	Qualifications & Experience	Skills Required	Numbers

SECTION D: Training & Upskilling Needs

Particulars	Details
Annual Training Budget (INR in Crore)	
Number of Employees Trained Annually	
Preferred Training Mode	☐ Classroom ☐ Online ☐ Onsite
Training Staff	☐ In-house ☐ Third party ☐ Both
Key Areas for Training	
Certification Required	☐ Yes ☐ No

SECTION E: Key Challenges Regarding Manpower

☐ Lack of skilled manpower

☐ High attrition

☐ Shortcomings in certain skillsets (Specify)

☐ Lack of availability of courses for bridging skill gaps

☐ Lack of training staff

☐ Others: _____

SECTION F: Recommendations from Industry

SECTION G: Surveyor Notes

