Knowledge Paper on

Looking into the Next Decade: Emerging Energy Technologies and Workforce Transformation in India

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Knowledge Partner

Acknowledgements

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Authors

Aniket Tiwari, Research Associate, TERI

Prachi Saini, Associate Fellow, TERI

Reviewers

AK Saxena, Senior Fellow and Senior Director, TERI

Alekhya Datta, Fellow and Director, TERI

Dr. Suneel Pandey, Senior Fellow and Director, TERI

Kiran Kumar Alla, Senior Fellow and Director, TERI

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Foreword

As India advances on its journey towards a clean, connected, and resilient future, the need to align technological innovation with workforce preparedness has never been more urgent. Our national commitments, achieving net-zero emissions by 2070 and building 500 GW of non-fossil capacity by 2030, demand not only bold investments in green hydrogen, waste-to-energy, semiconductors, and AI-driven systems, but also a parallel transformation of the workforce that will power and sustain these innovations.

This paper 'Looking into the Next Decade: Emerging Energy Technologies and Workforce Transformation in India', brings together valuable insights on emerging technologies, market trends, investment flows, and skill imperatives that are central to India's energy transition. It rightly emphasizes that the energy future of our nation will not be shaped by technology alone, but by the skilled manpower and collaborative institutions that enable its adoption and scaling.

I acknowledge the contributions of TERI for their rigorous analysis and the actionable roadmap presented in this paper. The work underlines the importance of industry–academia partnerships, national skilling programs, and global best practices as we prepare our workforce for the opportunities and challenges of the coming decade.

The Indian Chamber of Commerce is proud to partner in this endeavour, reinforcing our mission to act as a bridge between policy, industry, and knowledge institutions. I am confident that the findings of this report will prove invaluable to policymakers, business leaders, and educators, guiding India in its aspiration to become a global leader in clean energy and sustainable development.

Dr. Rajeev Singh Tyagi
Director General
Indian Chamber of Commerce

About TERI

The Energy and Resources Institute (TERI) has a long record of producing rigorous, scenario-based analyses that underpin India's clean-energy policymaking. Its flagship study "India's Electricity Transition: Pathways to 2050" models four demand–supply trajectories for the power sector, quantifying investment needs of USD 1.2–1.6 trillion and showing how a four-fold rise in electricity demand can be met with high shares of renewables, storage and flexible thermal assets. Complementing this mid-century lens, TERI's 2022 discussion paper "Roadmap to India's 2030 Decarbonization Target" maps sector-wise abatement options consistent with India's updated NDC, identifying least-cost pathways to reach a 50% non-fossil power share and 45% emissions-intensity reduction by 2030. TERI also delivers granular, state-level action plans: the "Low-Carbon Pathways for Madhya Pradesh" report (2023), prepared with the state government, details technological and fiscal measures that could cut MP's power-sector emissions 35% below BAU by 2030 while boosting jobs and GDP. These studies along with TERI–Shell assessments of national low-carbon trajectories and numerous policy briefs on green hydrogen, battery storage and just transition, demonstrate the institute's breadth of expertise and its sustained commitment to data-driven insight for India's energy transition, providing valuable context for stakeholders across India.

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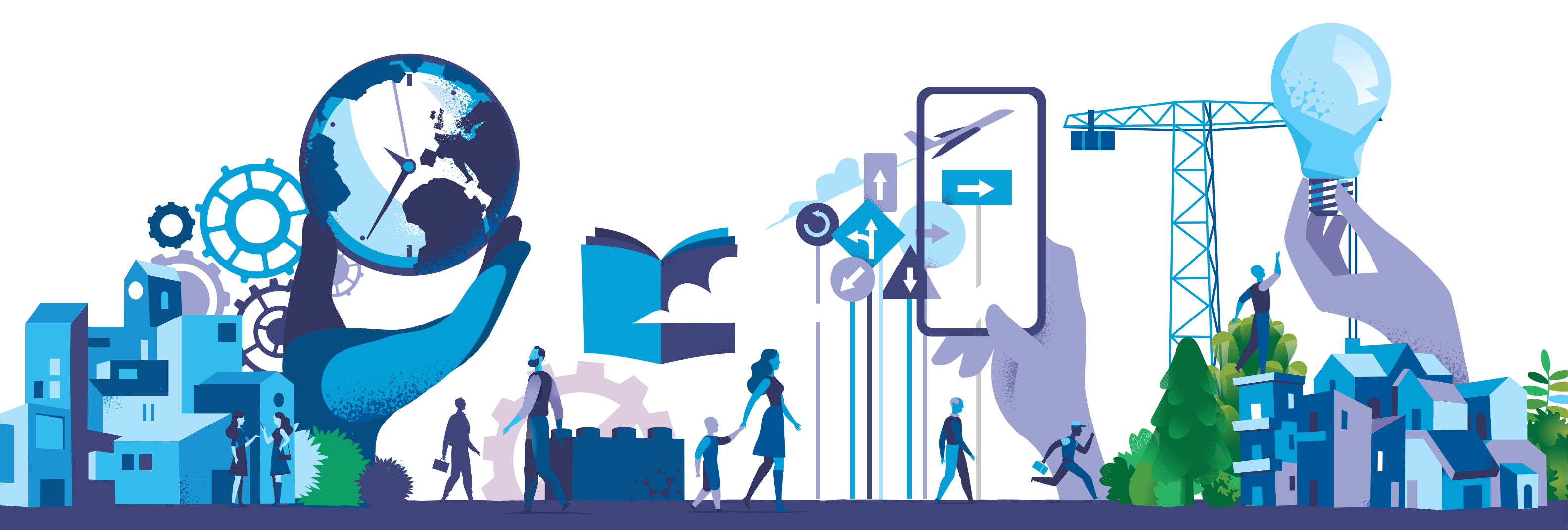
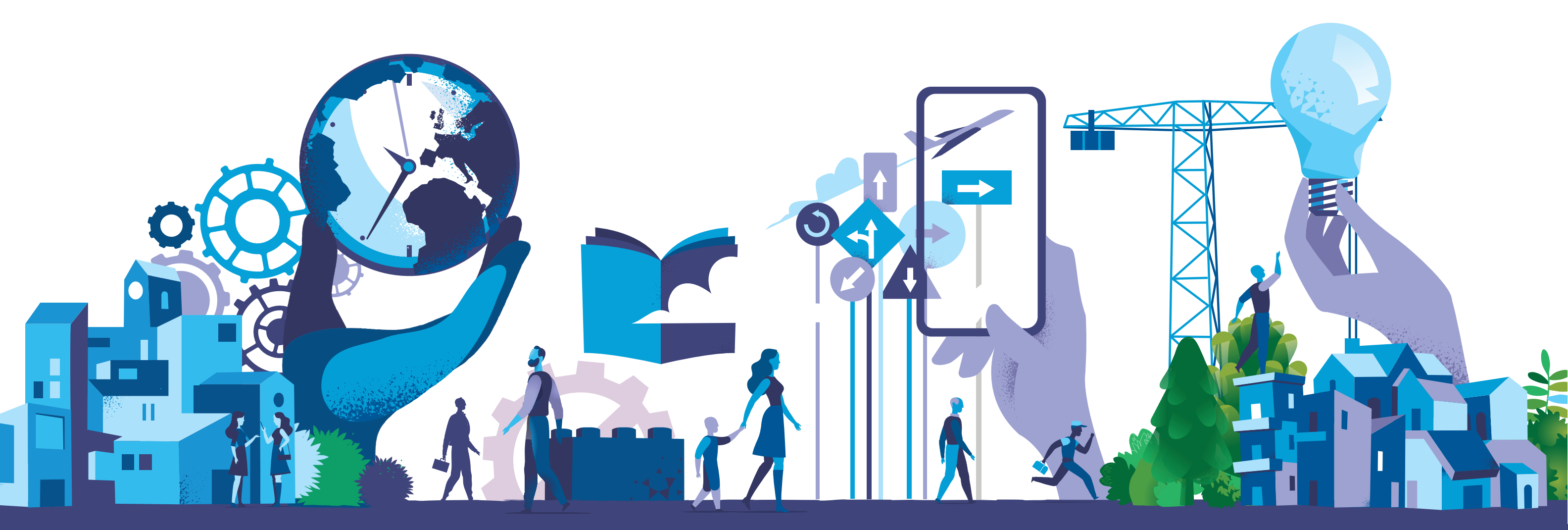


List of Abbreviations

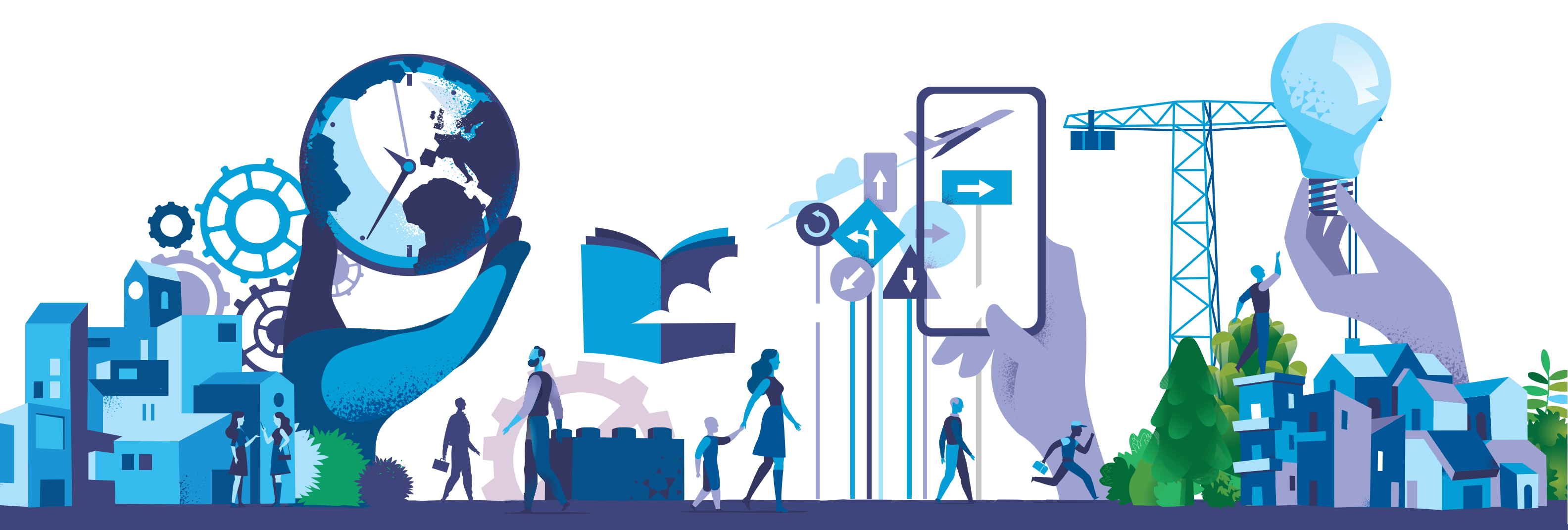
AD	Anaerobic Digestion
ADAS	Advanced Driver-Assistance Systems
AEM	Anion Exchange Membrane
AI	Artificial Intelligence
AICTE	All India Council for Technical Education
AMI	Advanced Metering Infrastructure
AMS	Analog/Mixed-Signal
ASME	American Society of Mechanical Engineers
ATEX	ATmosphères EXplosibles
ATMP	Assembly, Testing, Marking & Packaging
BCG	Boston Consulting Group
BEOL	Back End of Line
BIS	Bureau of Indian Standards
BoP / BOP	Balance of Plant
CAPEX	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
CBG	Compressed Bio-Gas
CEA	Central Electricity Authority
CEMS	Continuous Emissions Monitoring System.
CfD	Contracts for Difference
CNC / CM/PM	Corrective Maintenance / Preventive Maintenance
CMRT	Certified Maintenance & Reliability Technician
CMP	Chemical Mechanical Planarization.
CNG	Compressed Natural Gas
CoE	Centre of Excellence
CPC/PCB	(Central/State) Pollution Control Board
CVD	Chemical Vapor Deposition
DC	Data Centre
DCS	Distributed Control System
DFM / DFT	Design for Manufacturability / Design for Test
DISCOM	Distribution Company
DLI	Design Linked Incentive
DRI	Direct Reduced Iron
EDA	Electronic Design Automation
EPC	Engineering, Procurement & Construction

ESG	Environmental, Social & Governance
EUV	Extreme Ultraviolet (lithography)
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FEOL	Front End of Line
FOWLP	Fan-Out Wafer Level Packaging
FTE	Full-Time Equivalent
GaN	Gallium Nitride
GDSII	Graphic Design System II
GH2	Green Hydrogen
GHPO/HPO	(Green) Hydrogen Purchase Obligation
GOBARdhan	Galvanizing Organic Bio-Agro Resources Dhan
GoI	Government of India
GW/GWh	Gigawatt / Gigawatt-hour
HAZID / HAZOP	Hazard Identification / Hazard and Operability Study
HEIs	Higher Education Institutions
HIC	Hydrogen-Induced Cracking
HSE	Health, Safety & Environment.
H_2	Molecular Hydrogen
I&C	Instrumentation & Control
IEC	International Electrotechnical Commission
IGBT	Insulated-Gate Bipolar Transistor
IGSSV	IGSS Ventures Pte Ltd.
IIoT	Industrial Internet of Things
IISc	Indian Institute of Science
IIT / NIT	Indian Institutes of Technology / National Institutes of Technology
IMEC/imec	Interuniversity Microelectronics Centre
IMM	Industrial Maintenance Mechanic
IP	Intellectual Property
ISGF	India Smart Grid Forum
ISM	India Semiconductor Mission
ISMC	International Semiconductor Manufacturing Corporation
ISO	International Organization for Standardization
IT/ITeS	Information Technology / IT-enabled Services
ITI	Industrial Training Institute



IEC/ISO	International Electrotechnical Commission/ International Organization for Standardization
IoT	Internet of Things
JSS	Jan Shikshan Sansthans
JVs	Joint Ventures
LCOH	Levelized Cost of Hydrogen
LH_2	Liquid Hydrogen
LOTO	Lockout/Tagout
MEA	Membrane Electrode Assemblies
MeitY	Ministry of Electronics & Information Technology
MLOps	Machine Learning Operations
MMT / MTPA	Million Metric Tonnes / Million Tonnes Per Annum
MNRE	Ministry of New & Renewable Energy
MoE	Ministry of Education
MoEFCC	Ministry of Environment, Forest & Climate Change
MoHUA	Ministry of Housing & Urban Affairs
MoP	Ministry of Power
MoU	Memorandum of Understanding
MSDE	Ministry of Skill Development & Entrepreneurship
MSME	Micro, Small & Medium Enterprises
MW/MWh	Megawatt / Megawatt-hour
NAPS	National Apprenticeship Promotion Scheme
NCrF	National Credit Framework
NGHM	National Green Hydrogen Mission
NITI Aayog	National Institution for Transforming India
NSDC	National Skill Development Corporation
NSDM	National Skill Development Mission
NSQF	National Skills Qualification Framework
NTPC	National Thermal Power Corporation
O&M	Operations & Maintenance
OEM	Original Equipment Manufacturer
OSAT	Outsourced Semiconductor Assembly & Test
OSHA	Occupational Safety & Health Administration
OT / ICS	Operational Technology / Industrial Control Systems
PDK	Process Design Kit
PEM	Proton Exchange Membrane
PESO	Petroleum & Explosives Safety Organisation
PFD/PSA	Pressure Swing Adsorption
PLI	Production Linked Incentive
PNGRB	Petroleum & Natural Gas Regulatory Board.
PPA	Power Purchase Agreement

PPP	Public–Private Partnership
PSM	Process Safety Management
PSU	Public Sector Undertaking
PUE	Power Usage Effectiveness
PV	Photovoltaic
PVD	Physical Vapor Deposition
QA/QC	Quality Assurance / Quality Control
QP	Qualification Pack
R&D	Research & Development
RDF	Refuse-Derived Fuel
RDSS	Revamped Distribution Sector Scheme
RE	Renewable Energy
REC	Renewable Energy Certificate
RTC	Round-the-Clock
RTL	Register Transfer Level
SATAT	Sustainable Alternative Towards Affordable Transportation
SCADA	Supervisory Control & Data Acquisition
SCGJ	Skill Council for Green Jobs
SCL	Semiconductor Complex Limited
SIGHT	Strategic Interventions for Green Hydrogen Transition.
SiC	Silicon Carbide
SLA	Service Level Agreement
SOEC	Solid Oxide Electrolysis Cell
SOP	Standard Operating Procedure
SSC(s)	Sector Skill Council(s)
STEM	Science, Technology, Engineering & Mathematics
TAM	Total Addressable Market
TIA	Telecommunications Industry Association
TIIS	Tata Indian Institute of Skills
TRL	Technology Readiness Level
TSMC	Taiwan Semiconductor Manufacturing Company
UGC	Univer



1. Introduction: India's Path to a Clean, Connected, and Resilient Future

India stands at a critical juncture in its energy and economic development journey. As the country strives to achieve net-zero emissions by 2070 with intermediate targets of achieving 500 GW of non-fossil fuel-based electricity generation capacity achieving 40-45% reduction in emissions intensity by 2030,[1] it is simultaneously navigating the rapid evolution of energy technologies and the imperative to build a future-ready workforce.

Complementing these broad goals are specific missions targeting Green Hydrogen, Semiconductor manufacturing, and advancements in Artificial Intelligence (AI) & Data Centers, alongside initiatives for Waste to Energy. These national strategies position India as a significant player in clean technology innovation, manufacturing, and potential export competitiveness on the global stage. However, their successful implementation hinges on the availability of skilled manpower capable of designing, installing, operating, maintaining, and innovating within these new paradigms.

India's global positioning in clean technology manufacturing and innovation is strengthening, supported by strategies like the National Hydrogen Mission, the Production Linked Incentive (PLI) schemes, and growing exports in renewable energy components. At the same time, the country is expanding its waste-to-energy capacity and exploring circular economy models to address urban sustainability challenges.

Workforce transformation is central to this transition. The Ministry of Skill Development and Entrepreneurship (MSDE), in collaboration with industry partners, is rolling out green skill programs, upgrading Industrial Training Institutes (ITIs), and establishing Centres of Excellence to align workforce capabilities with technological advancement. These efforts are essential to ensure that India's demographic dividend translates into a skilled, resilient, and adaptive workforce.

This knowledge paper explores the intersection of emerging energy technologies and workforce transformation in India. It examines policy frameworks, technological trends, skilling initiatives, and strategic pathways that will shape India's clean, connected, and resilient future over the next decade.

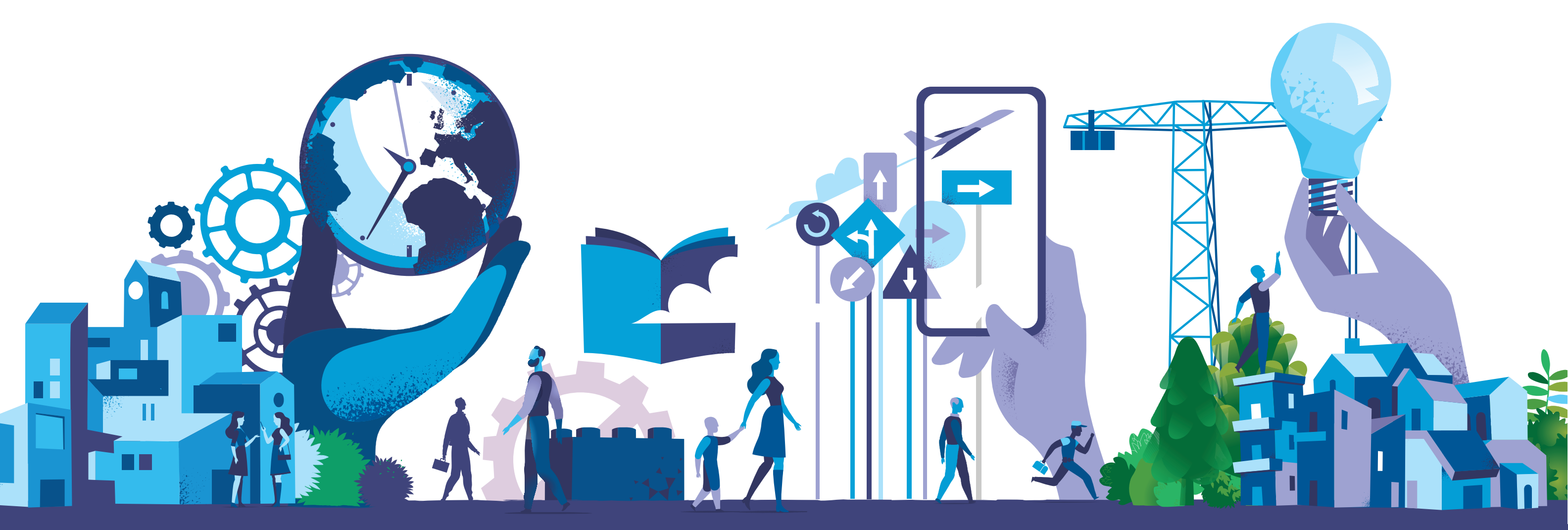
2. Emerging Technologies Shaping India's Energy Transition

2.1 Green Hydrogen

2.1.1 Technology Overview

Green hydrogen refers to hydrogen gas produced with near-zero greenhouse gas emissions, seen as a vital solution for decarbonizing "hard-to-abate" sectors like steel, fertilizer (ammonia), refineries, heavy transport and chemicals.[2] The primary hydrogen production pathway is electrolysis of water, where renewable electricity splits water into hydrogen (H^2) and oxygen. Commercial electrolyzer technologies include Alkaline and PEM (Proton Exchange Membrane) electrolyzers, both at high Technology Readiness Level (TRL) 9 (fully commercialized).[3] Newer electrolyzer types like Anion Exchange Membrane (AEM) and Solid Oxide Electrolysis (SOEC) are in the R&D-to-demonstration stage (TRL ~5–6), aiming for future cost and efficiency improvements. Another pathway is production of hydrogen from biomass or biowaste gasification, which is currently less mature[4] (TRL 5–6). In this process, agricultural residue or municipal solid waste is converted to hydrogen-rich syngas, offering a dual benefit of waste management and fuel production. India is piloting such bio-hydrogen projects, though challenges remain in scaling up to economically viable plant sizes.[5]

Beyond production methods, integrating green hydrogen into industrial processes is a key focus. In steelmaking, for example, hydrogen can serve as a reduction agent to produce steel with far lower CO_2 emissions than coal-based methods. Plants that use natural gas are Hydrogen Direct Reduced Iron (DRI) ready but would need modifications in the plant equipment to handle Hydrogen. Major steel firms in Europe and India are experimenting with hydrogen-based DRI processes, although widespread deployment may take years to materialize.[6] In fertilizer production (ammonia), and in oil refineries, hydrogen is already used extensively, currently derived from natural gas (grey hydrogen). There have been studies that assessed mandating some percentage of Hydrogen usage can be done without increasing the cost of end product significantly. While costs are expected to fall with demand and scale, mandates can start driving demand in these two sectors[7], so transitioning to green hydrogen is technically straightforward once cost barriers are overcome. Hydrogen can also fuel long-haul trucks, shipping, and possibly aviation (via synthetic fuels),



though fuel cells and related infrastructure for transport are still developing. Overall, the technology for green hydrogen use is largely known and in many cases is at TRL 8–9; the core challenge is achieving competitive cost and scaling up infrastructure, rather than fundamental R&D. India's National Green Hydrogen Mission launched in 2023 reflects this, emphasizing pilot projects across these applications and advancing electrolyzer manufacturing to prepare for large-scale adoption.

2.1.2 Market Size & Growth

Globally, hydrogen demand is around 90–100 million tonnes per year,[8] mainly for refineries and fertilizer production, and over 99% of this is fossil-derived (grey hydrogen).[9] Green hydrogen currently accounts for only a negligible share of this market (<1%), but momentum is building rapidly. India has set an ambitious production target of 5 million metric tonnes (MMT) of green hydrogen per annum by 2030, backed by the National Green Hydrogen Mission.[7] This would be a massive jump from virtually zero green hydrogen production today, India's commissioned green hydrogen capacity was under 0.01 MMT, highlighting the enormous growth required. Achieving the 2030 goal would not only decarbonize domestic industrial hydrogen use but potentially make India a net exporter of green ammonia/hydrogen. India aspires to capture ~10% of the global green hydrogen market in the long term, with plans to export up to 10 MMT per year in the future.[10]

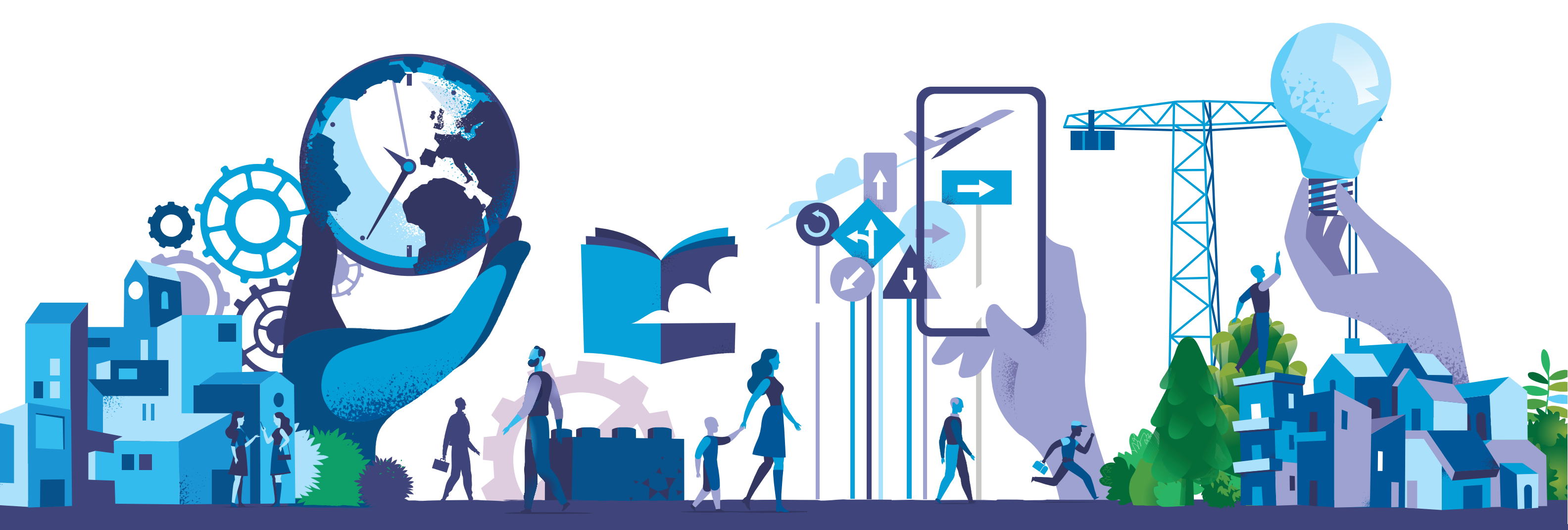
Market growth is pivotal for the reduction in cost trends. Today, green hydrogen produced via electrolysis in India is estimated to cost around $4–6 per kg, 2-3x of the $2 per kg cost of grey hydrogen from natural gas.[11] This cost gap is expected to narrow as renewable electricity prices continue to fall, electrolyzer manufacturing scales up, and learning curves improve. India's strategy should be to build demand and allow scale to drive down costs. An additional 1 MTPA demand could lead to a 15-20% reduction, eventually reaching below the current cost GH2 production at the 5 MTPA level.

2.1.3 Investment Landscape

India's green hydrogen push has catalyzed a flurry of activity among both public and private sector players. On the policy front, the National Green Hydrogen Mission provides ₹19,744 crore (~$2.4 billion) as initial government funding, including incentives for domestic electrolyzer manufacturing and for green hydrogen production (the SIGHT scheme). This is expected to leverage much larger private investments, with the Mission projecting over $100 billion in overall investments by 2030. Key public-sector companies are taking the lead: NTPC, the largest power utility is investing in green hydrogen and ammonia projects,[12] and Fertilizer PSUs have issued tenders to procure green hydrogen/ammonia for their plants. Major private conglomerates have also announced bold plans; Reliance Industries intends to build one of the world's largest integrated renewable-to-hydrogen complexes in Gujarat, targeting green H_2 at ~$1/kg in the long term,[13] and Adani Group has partnered with TotalEnergies to develop green hydrogen ecosystems. Engineering giants like Larsen & Toubro have entered electrolyzer manufacturing, while startups are innovating in areas like electrolysis technology, hydrogen storage, and fuel cells. Recent tenders of SECI under the SIGHT Scheme has broken the barrier of INR 50/kg for production of green ammonia at Paradip Odisha.[14, 15]

2.1.4 Challenges & Opportunities

Key Areas	Challenges	Opportunities
Cost gap vs. grey H_2	Renewable/green H_2 is still ~1.5–6× costlier than unabated fossil H_2, keeping offtake cautious[16]	India's ultra-low RE tariffs (solar bids to ₹2.15/kWh) and learning curves can narrow LCOH this decade[17]
Electrolyzers: CAPEX & supply chain	Imported PEM systems have a baseline installed cost ~$2,000/kW; global manufacturing is concentrated (China ~60%)[18]	Domestic push: SIGHT tender for 1.5 GW/yr electrolyzer manufacturing; Ohmium's 2–4 GW India gigafactory[19]
Power input (RE cost/availability)	H_2 economics need sustained, high-CF, cheap RE; RTC (firm) RE is still materially pricier than standalone solar/wind (e.g., RTC award at ₹5.07/kWh)[20]	Falling solar/wind tariffs and hybridization enable low-cost dedicated power for H_2 plants.
Transport & storage infrastructure	India lacks dedicated H_2 pipelines; PNGRB notes the Act must be amended to regulate pure-H_2 lines and related standards[21]	NGHM hub development plus near-term use of ammonia as a carrier (dominates announced trade) can jump-start logistics
Demand creation / offtake risk	Buyers hesitate to pay the green premium; industry is urging Hydrogen Purchase Obligations (HPO/GHPO)[22]	Targeted policies (e.g., GHPO, CfD-style support) could unlock ~2.1–5 MMT demand by 2030[23]
Standards, certification & safety	While India has a Green H^2 Standard, broader testing/certification & safety frameworks are still being built out[24]	The ≤2 kg CO_2e/kg H_2 standard aligns exports with global expectations and future EU CBAM requirements from 2026[25]
Industrial integration (hard-to-abate)	Retrofitting burners, process lines & training the workforce adds time/cost to early projects[26]	NGHM targets (5 MMT H_2, ~50 MMT CO_2/yr abatement, ~600k jobs) unlock deep decarbonization in refining, fertilizer, steel.[27]
Exports & global markets	Shipping derivatives (e.g., ammonia) adds conversion losses and faces cost/safety hurdles[28]	CBAM (2026) boosts demand for low-carbon imports; analyses foresee ammonia-led trade where India can participate[29]
Mobility & long-duration storage	Sparse refueling infra; early deployments only[30]	Govt-backed pilots (37 vehicles, 9 stations) and NTPC's FCEV buses in Leh build capabilities; H_2 also offers grid-balancing storage
Skills & workforce readiness	Shortage in stack/BoP engineers, H_2 safety/process specialists, compression & storage logistics, and O&M techs; misaligned curricula; limited hands-on line-time; low apprenticeship uptake; thin inspection/certification capacity.	Workforce transition from refineries/chemicals/gas utilities via recognition-of-prior-learning—large, low-latency talent pool.



2.2 Waste-to-Energy

2.2.1 Technology Overview

Waste-to-Energy (WtE) technologies convert various waste streams into usable energy, typically electricity or heat, and sometimes fuel, thus addressing two issues at once: waste management and energy generation. There are several key WtE pathways, each suited to different waste types and conditions:

WtE Pathway	Process Description	Suitable Waste Types	Technology Readiness Level (TRL)	Key Outputs	Advantages	Challenges / Limitations	Status in India
Incineration (Combustion)	Direct burning of MSW in waste boilers to produce steam and power.[31]	Segregated MSW with reasonable calorific value[32]	TRL 9 – Fully commercial worldwide.	Electricity, heat.	» Reduces waste volume by ~90% » Neutralizes biological hazards.	» Requires proper segregation » High air-pollution control needs	5–25 MW plants operational in multiple cities
Gasification	Partial oxidation at 500–1500[33] °C → syngas production	Dry, homogeneous wastes like RDF, Agri/industrial waste	TRL 7–8 Demonstrated, not yet fully commercial.	Syngas (for power, hydrogen, chemicals).	» Potentially higher efficiency, lower emissions.	» Sensitive to feedstock quality, needs preprocessing. » May require air pollution control	Pilot projects and integrated WtE plants being tested.
Pyrolysis	Thermal cracking in absence of oxygen → char, oils, gas [34]	Segregated plastics, tyres, biomass	TRL ~7 Proven in niche applications	Liquid fuels (bio-oil), char, gas.	» Converts plastic-rich streams into usable oil	» Not suitable for mixed MSW » High costs at scale. » May require air pollution control	Several small units converting plastics to industrial oil.[35]
Anaerobic Digestion (Biomethanation)	Microbial breakdown of organics in oxygen-free digesters → biogas.[36]	Food waste, agri residues, manure, sewage sludge.	TRL 9 – Mature and widely deployed	Biogas (electricity, bio-CNG), organic fertilizer.	» Ideal for wet organic waste » Produces renewable fuel & compost.	» Needs source segregation » Digestate handling required	Decentralized bio methanation plants growing rapidly; supported by SATAT initiative.
Plasma Arc Gasification	Plasma arc (>3000 °C) breaks waste to syngas + vitrified slag.[37]	Hazardous, medical, e-waste.	TRL 5–6 –for specialized waste; lower maturity for large mixed MSW due to scale-up, cost, and regulatory barriers.[38]	Clean syngas, inert slag.	» Can treat hazardous waste safely.[39]	» High CAPEX & OPEX · Not viable for large MSW volumes.	Experimental biomedical waste units under testing. Not many commercial units due to high cost and costly maintenance

2.2.2 Market Size & Growth

India generates an enormous amount of solid waste, estimated at ~150,000 tonnes per day of municipal solid waste (MSW) as of 2023,[40] and this is projected to grow steadily with urbanization (1–1.3% increase per capita annually).[41] The energy potential contained in urban and industrial organic waste in India is about 5,690 MW,[42] according to the Ministry of New and Renewable Energy (MNRE). This figure represents the theoretical electricity generation capacity if all such waste were processed via WtE technologies. The vast majority of waste still ends up in landfills or open dumps, with only a small fraction currently treated through WtE facilities. Growth in the WtE sector has been modest, until 2015, India's waste-to-energy (WtE) sector was limited to only a few large plants. By late 2020, the total installed capacity had increased to approximately 250–300 MW, and this capacity has nearly doubled in the subsequent years.[43] As of July 2025, India's installed WtE capacity was only about ~855 MW from off-grid and grid connected, i.e. roughly 15% of the potential. The central government's National Bioenergy Programme, launched in 2022 includes a dedicated sub-program for Energy from Urban, Industrial and Agricultural Wastes, which provides capital subsidies and other incentives to facilitate new WtE projects. This has reinvigorated interest, dozens of cities have WtE projects in planning or tender stages, ranging from small bio-methanation plants to large mass-burn incinerators. The market is also being driven by the chronic shortage of urban land for new landfills and the stricter enforcement of waste management rules.

2.2.3 Investment Landscape

The WtE sector in India involves a mix of public and private investment, often structured as Public-Private Partnerships (PPP) given the municipal responsibility of waste management. On the public side, city municipal corporations usually provide the raw material (waste) and often a tipping fee or viability gap funding to make projects viable. The central government (through MNRE) and some state governments provide capital subsidies or generation-based incentives. For instance, under MNRE's program, financial assistance covers aspects like interest subsidy on loans for commercial projects and 20%+ capital subsidy for innovative technologies.[44] Urban local bodies may also sign long-term power purchase agreements (PPAs) with WtE plants at relatively high tariffs (₹6–8 per kWh) to ensure revenue, since pure market-based power sales would not recover costs given cheaper alternatives. Private players have taken on WtE projects as developers or operators. Notable companies include Jindal ITF (which runs the large 24 MW Okhla WtE plant in Delhi), Antony Waste Handling Cell (commissioned the new 14 MW plant in Maharashtra, Ramky Enviro, IL&FS Environmental. These players often form SPVs (special purpose vehicles) to build-own-operate WtE plants on a 20–30-year concession agreement with a municipality. The investment typically involves high upfront cost: WtE plants can cost ₹10–15 crore per MW, due to the need for fuel handling and pollution control equipment. This has meant that securing financing can be challenging, banks have in the past been hesitant due to under performance of WtE plants. To incentivize investment, the National Bioenergy Programme (Phase I: 2022–26) allocated significant funds to Waste to Energy Programme which provides central financial assistance up to ₹50 million per MW for MSW-to-power projects and ₹4 million per 4800 m^2 of biogas for bio-methanation projects.[45]

2.2.4 Challenges & Opportunities

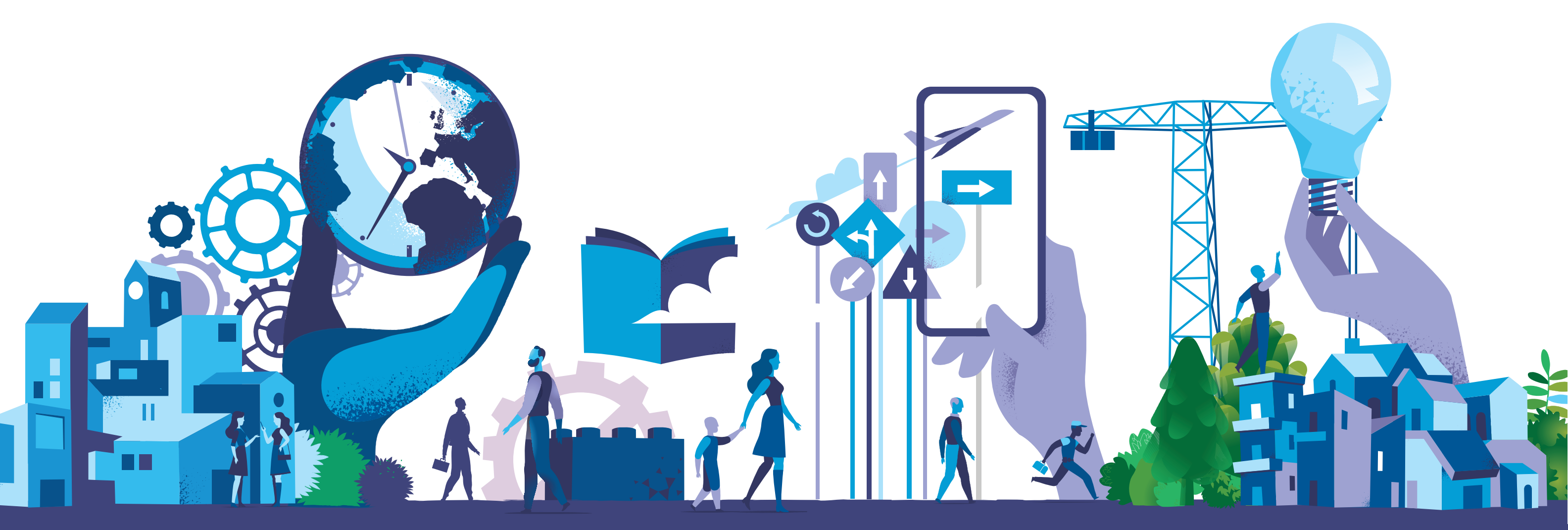
Key Areas	Challenges	Opportunities
Feedstock Quality & Composition	» Indian MSW often has 40–52% moisture content, high organic content (~55-60%) → low heating value, difficult for incineration or combustion-based WtE.[46] » Poor source segregation; contamination during transport and storage; inert materials / wet waste reduce efficiency.[47]	» Improving segregation at source, pre-processing (drying, sorting) can raise calorific value and reduce downtime. » RDF (Refuse Derived Fuel) options for mixed waste if contamination is reduced. » Bio methanation more apt for wet organic fractions. Supported by studies noting good performance of biological WtE when feed mix is more consistent
Regulatory / Policy Aspects & Public Acceptance	» Weak enforcement of waste rules (e.g. Solid Waste Management Rules 2016) around segregation, emissions, ash disposal[48] » Public mistrust / protest due to odors, emissions, health risks specifically around existing WtE incinerators, leading to delay and complication in clearances.[49]	» Moving beyond the existence of strong policy frameworks, risk reduction hinges on improved enforcement and governance. This requires a concerted focus on enhancing monitoring, ensuring accountability, and fostering transparency. » Transparent emission monitoring & community engagement can improve social license to operate. » Regulations or incentives for landfill diversion, carbon credits, polluter-pays can tilt economics in favour of clean WtE. Implications in recent studies pointing to this.[50] » Proper project siting and designing of WtE plants reduce conflict with neighborhood
Financial / Economic Viability	» High capital costs, operational costs (e.g. pollution control, ash handling) make WtE more expensive than wind/solar for electricity per kWh) » Tipping fees, waste supply contracts, discom willingness to buy power are often weak / risky. Many projects struggle with revenue certainty.	» Opportunities for blended finance, PPPs; policy instruments like viability-gap funding or guaranteed tariffs. » Multiple revenue streams possible: power, tipping fees, by-products like compost, bio-fertilizer, carbon credits. » Increasing demand for biofuels / Compressed Biogas (CBG) under government programs like SATAT can improve revenue models. Supported in recent reviews.[51]

Key Areas	Challenges	Opportunities
Operational / Infrastructure Challenges	» Difficulty in securing land, especially near cities for plants & buffer zones. » Ash / residual waste disposal, heavy metal content, environmental risk. » Inconsistent supply of contracted waste due to informal recycling, logistical gaps; transport/storage contamination .	» Opportunity for decentralized or smaller scale WtE or biomethanation plants closer to waste sources to reduce transport and logistic losses. » Use of co-processing (industrial plants like cement kilns) to use RDF or part of MSW as fuel, reducing coal use. » Innovation in modular technologies, better emission/ash control can lower operating and environmental risk. Recent research highlights modular gasifiers, improved emissions control as high potential.
Environmental & Health Impacts	» Past and ongoing emissions issues (particles, dioxins, odor) have led to plant shutdowns or public backlash. » Ash/digestate often poorly handled, potential heavy metal contamination or groundwater / soil exposure. » Greenhouse gas trade-offs: unless capture done well, methane from landfill vs emissions from incineration etc.	» Properly designed WtE plants with stringent emissions control can reduce public health risk relative to uncontrolled dumping or open burning. » Landfill gas capture and emission reductions (avoided methane) can improve climate credentials. Studies show GHG benefits if waste is used rather than dumped. » Opportunity for using residuals (ash, digestate) in construction, agriculture (if safe), creating circularity.
Skills & Workforce Readiness	» Shortage of plant-ready operators/technicians and CEMS/ HSE assessors; limited hands-on training and weak apprenticeship pipeline.	» City/ULB operator academies with OEM-led multi-skilling and SCGJ certification, scaled via NAPS/RPL and simulators/mobile labs to drive high placements in urban clusters.

2.3 Semiconductor Manufacturing

2.3.1 Technology Overview

Semiconductor components, the microchips that power modern electronics are a strategic linchpin in clean energy systems. From solar panels and wind turbines to electric vehicles (EV) and smart grids, virtually every clean technology is underpinned by semiconductors. For instance, solar photovoltaic



(PV) modules themselves are made of semiconductor materials (silicon wafers), and their inverters use high-power transistors to convert DC to AC. Wind turbines and EV drivetrains rely on advanced power electronics (IGBTs, MOSFETs) for efficient operation, which are semiconductor devices. Smart grid infrastructure, battery management systems, electric vehicle chargers, energy storage inverters, and IoT sensors for energy efficiency all contain microchips for control, communication, and optimization. Thus, ensuring a robust supply of semiconductors is increasingly seen as vital for energy transition security, a lesson underscored by recent global chip shortages that slowed EV production and renewable energy projects worldwide. However, semiconductor manufacturing capability is highly concentrated globally, and India has historically had *minimal presence* in this field. The technology for chip fabrication (fabs) is extremely complex (nanometer-scale lithography, ultra-clean environments, etc.), but it is mature at a global level. India's challenge is not about developing new semiconductor technology from scratch, but about establishing domestic manufacturing capacity for existing technologies, essentially an adoption and scale-up challenge. Currently, India is one of the world's largest consumers of semiconductors (given its big electronics and automotive market) but produces almost none domestically, importing an estimated 100% of its high-end chip needs. This dependency raises concerns about supply chain security.

2.3.2 Market Size & Growth

India's semiconductor market is already large and rapidly growing, driven by exploding demand for electronics, smartphones, electric vehicles, and IoT devices. In 2019, India's semiconductor consumption was valued around $21–22 billion; this was projected to triple to ~$64 billion by 2026.[52] By 2030, estimates range from $100 billion to $110 billion, reflecting a CAGR of roughly 15–18%.[53] To put that in context, India could account for ~6–8% of the global semiconductor market by 2030, global market size in 2021 was ~$500 billion, expected to exceed $1 trillion by 2030 given trends. Much of this demand comes from consumer electronics and IT hardware, but a significant portion is tied to clean energy and transportation: EVs, for instance, require many more chips per vehicle than traditional cars for battery management, on-board chargers, inverter/converter, Advanced Driver-Assistance Systems (ADAS) sensors, etc.; similarly, solar inverters and wind turbine controllers require specialized power semiconductors.

Despite this large market, domestic production is negligible**,** India has no commercial-scale silicon fab for logic or memory chips as of 2025. There are only small-scale facilities like SCL (Semiconductor Complex Ltd., a government-run fab with older-generation 180 nm technology mainly for strategic use) and some Gallium Nitride (GaN) and Gallium Arsenide prototype lines in labs. This means essentially none of India's semiconductor demand is met domestically today. All the chips in our solar inverters, EVs, smart meters, and laptops are imported from foundries in Taiwan, South Korea, the US, Europe or China. The government initially set a vision that India should produce perhaps 10% of its semiconductor needs in the near-to-midterm, capturing a slice of the TAM (Total Addressable Market) as domestic manufacturing. The Semiconductor Mission launched a $10 billion incentive package in 2021/22, which has attracted proposals for new fabs. In 2023, at least three consortia had applied:

» Vedanta-Foxconn for a 28 nm logic fab in Gujarat,

» IGSS Ventures Pte Ltd (IGSSV), a Singapore-based company for a 65 nm analog fab, and

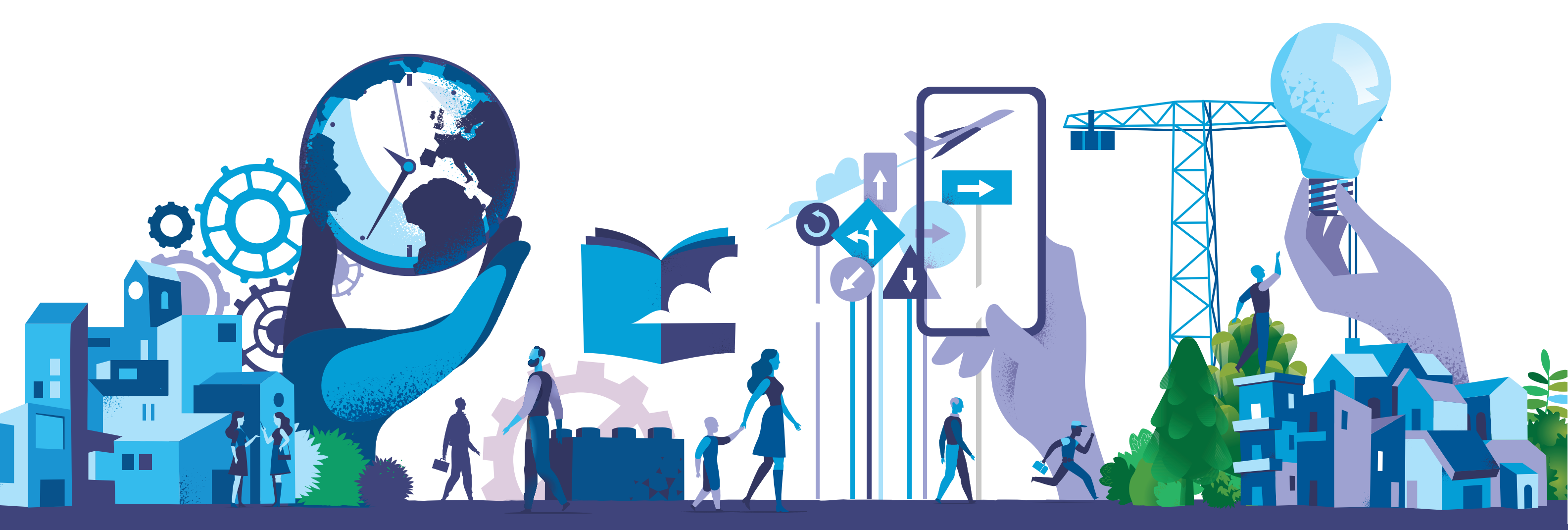
» ISMC (a consortium including NextOrbit and Tower Semiconductor of Israel) for a 65 nm analog fab in Karnataka.

2.3.3 Investment Landscape

The semiconductor manufacturing initiative in India is being driven top-down by government facilitation but ultimately requires the involvement of industry giants who have the technology and the appetite to invest. The Government of India has set up the India Semiconductor Mission (ISM) as a dedicated agency to coordinate proposals and incentives. The marquee incentive is the Production-Linked Incentive (PLI) for semiconductors, which covers up to 50% of capital expenditure for eligible projects, alongside state government incentives.[54] This level of support is crucial given that a state-of-the-art fab can cost $10–20 billion to build and equip and has a long payback period.[55] Micron Technology (US-based memory chip maker) became the first to commit with its Assembly, Testing, Marking, and Packaging (ATMP) facility in Gujarat, a $2.75 billion project with the central government and Gujarat state together funding 70% of the cost as subsidy.[56] This facility will take memory wafers (potentially made in Micron's fabs abroad) and perform the back-end processing to package them into chips. While not a full fab, it's a critical part of the value chain and will train thousands of workers in high-tech manufacturing.

2.3.4 Challenges & Opportunities

Theme	Challenges	Opportunities
Capital Intensity & Risk	» Cutting-edge fabs cost >$5 billion each, with 5+ year breakeven; execution risk is high[57] » Failure of early projects could deter future investors[58]	» 50% CapEx subsidy available under India Semiconductor Mission reduces investor burden[59] » Successful first fabs could attract more global investment, anchoring the ecosystem
Technology Access	» • Advanced tools (e.g. EUV lithography) face export restrictions; India must initially work on conventional nodes (65 nm/45 nm)[60]	» Partnerships with Tower, United Microelectronics Corporation (UMC), GlobalFoundries could provide step-up capability [61] » Government incentives include compound semiconductor & ATMP schemes, encouraging diversification
Supply Chain & Infrastructure	» Fab operations require 24/7 reliable power, millions of liters/day ultrapure water, specialty chemicals, India faces outages and water stress[62]	» Dedicated fab clusters like Dholera, Karnataka with captive power & water infrastructure planned » Supplier parks and incentives for local chemical/gas production to reduce import dependency[63]



Theme	Challenges	Opportunities
Talent & Skills	» Acute shortage of experienced fab managers, process engineers; <200 professionals in India with hands-on fab experience.[64] » Training new engineers takes years, slowing ramp-up.[65]	» Chips-to-Startup (C2S) program and MoUs with IMEC, Purdue, and others to train semiconductor engineers[66] » Opportunity to create thousands of high-value jobs and transfer know-how in chip design (VLSI, AI), manufacturing (fabs, equipment), testing (ATP), and supporting roles like supply chain, sales, and construction.[67]
Global Competition & Market Cyclicality	» Competing with US, EU, China, Korea for fab investments and scarce lithography tools.[68] » Semiconductor demand cycles could hit new entrants hardest during downturns[69]	» $100B+ domestic electronics market ensures captive demand for MCUs, power devices.[69] » Global "China+1" supply-chain diversification trend may channel more investment to India.[70]
Integration & Market Strategy	» Limited local ATMP/OSAT and downstream ecosystem means slower offtake for locally made chips.[71]	» Assembly, Testing, Marking, and Packaging (ATMP)/ Outsourced Semiconductor Assembly and Test (OSAT) plants already approved under ISM; integration with smartphone, EV, and appliance assembly will create a virtuous manufacturing cycle.[72] » Focus on power semiconductors, SiC/GaN devices for EVs/renewables positions India in high-growth niches[73]
Geopolitical & Strategic Context	» Risk that unstable policy or slow approvals push investors to proven hubs like Taiwan/USA[74]	» Local manufacturing reduces import dependence, secures critical infrastructure supply » Success of first fabs could attract major global players (TSMC, Samsung) for second-wave investments.[72]

2.4 Artificial Intelligence (AI) & Data Centres

2.4.1 Technology Overview

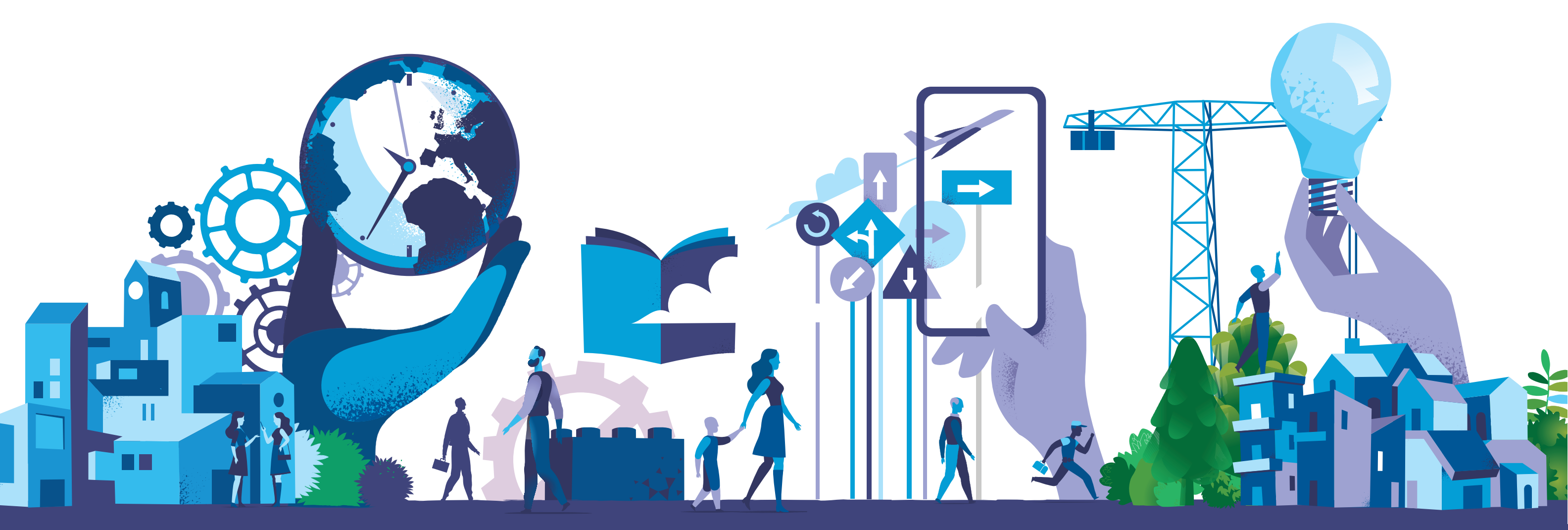
AI refers to computational techniques, like machine learning algorithms that enable machines to perform tasks that normally require human intelligence, such as pattern recognition, prediction, and optimization. In the context of energy, AI has emerged as a powerful tool to enhance efficiency, reliability, and decision-making. One major application is predictive maintenance of energy assets: AI algorithms analyze sensor data from equipment, turbines, transformers, solar inverters, etc., to predict failures or performance degradation before they happen. This reduces downtime and maintenance costs. AI plays a role in energy efficiency on the consumption side: smart thermostats, intelligent lighting systems, and industrial automation use AI to learn usage patterns and minimize energy waste without compromising comfort or output. In renewable energy integration, AI helps with energy storage optimization, charge/

discharge batteries for best economic value, smart charging of EVs based on traffic pattern and even trading in electricity markets, AI algorithms can learn and predict market price movements to schedule energy sales. Overall, AI in energy is less about new hardware and more about smart software overlaying the physical energy infrastructure, its TRL is high, many algorithms are already deployed globally, but adoption in India's energy sector is at an early to moderate stage and rapidly growing.

Data centres are the backbone facilities that house computer servers and data storage equipment. They enable cloud computing, internet services, and the processing of big data, which includes AI computations. Modern data centres are massive power consumers because thousands of servers running 24/7 consume electricity and give off heat that requires cooling. As India is undergoing a digital transformation with more internet users, digital services, e-governance, etc., the demand for data centres is skyrocketing. Additionally, global tech companies are setting up large hyperscale data centres in India to serve both domestic and regional customers. Data centres in India have been given infrastructure status, recognizing them as critical infrastructure akin to power plants or roads. Data centres consume a lot of energy, large ones can each draw tens of megawatts, and collectively data centres in India are expected to consume ~3% of the nation's electricity by 2030.[75] In terms of technology, data centre operations involve advanced power management systems like UPS, diesel generators for backup, battery energy storage systems now increasingly, and sophisticated cooling systems (traditional AC chillers, but also new methods like liquid cooling, evaporative cooling, etc. to reduce energy use). There is a trend toward green data centres, designing them with renewable energy supply, using AI to optimize cooling and server loads, and recycling waste heat. AI is actually used within data centres for tasks like dynamically adjusting cooling based on server workload.

2.4.2 Market Size & Growth

India's AI market was estimated at around $10 billion in 2023 and is expected to soar to over $180 billion by 2030, implying extraordinary growth, estimates put CAGR above 30%.[76] In the energy and utilities sector specifically, AI adoption is accelerating as companies recognize its value. A 2023 global survey by IBM found that 74% of energy and utility companies worldwide have implemented or are exploring AI solutions in their operations.[77] This indicates that AI in energy has moved from a pilot curiosity to the mainstream agenda for most large utilities. In India, major power sector players and distribution companies are running AI pilot projects, using AI for transmission line inspection via drones, or for theft detection in distribution networks by analyzing consumption patterns. The market for AI-based energy management systems, software that uses AI to control building energy, factory processes, etc., is also growing, with many startups and IT companies offering solutions to industries to cut energy use through AI analytics. Given India's large IT talent pool, there's also a burgeoning ecosystem of AI startups focusing on energy, such as those providing predictive maintenance for renewable farms or AI-driven analytics for grid balancing.



The data centre industry in India is on a steep upward trajectory, almost an exponential growth phase. As of 2024, India's total installed data centre capacity was around *1.4 GW,*[78] this corresponds to IT power load. This has roughly tripled since 2019 when capacity was about 350 MW.[79] Several reports project that by 2030, data centre capacity in India will reach between 9 to 17 GW.[80] A mid-range consensus is about 9–10 GW by 2030, which would be a ~6–7× growth from current levels. This explosion is driven by the proliferation of cloud computing, a boom in digital services, and data localization requirements, Indian regulations requiring certain data to be stored in-country. Already, over $14 billion of investment in data centres is planned for the next 5–7 years, from both foreign and Indian companies. The number of large data centre parks is rising in hubs like Mumbai, Chennai, Hyderabad, Bangalore and Delhi NCR, these cities offer connectivity and infrastructure needed. India now has over 260 data centres and ranks seventh globally in number of facilities. Notably, hyperscale players, like Amazon AWS, Microsoft, Google are rapidly expanding their footprint, and new players like AdaniConneX (Adani Group JV with EdgeConneX) and Hiranandani's Yotta are building massive campuses.

2.4.3 Investment Landscape

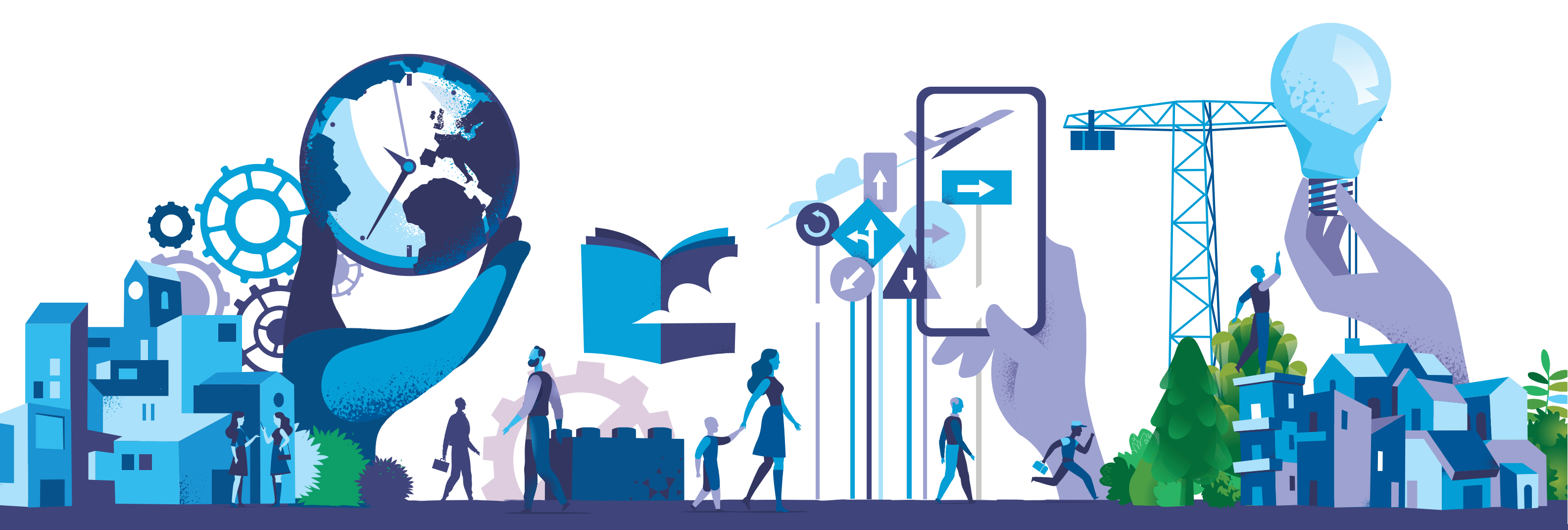
Investment in AI and data centres in India involves both big tech companies and policy support, with a strong involvement from the private sector. For Artificial Intelligence, much of the investment is in software development, startups, and digital infrastructure by companies. Tech majors like TCS, Infosys, Wipro and global firms like IBM, Google, Microsoft are investing in AI R&D in India, often in collaboration with sectors including energy. For instance, IBM's India labs have worked on AI solutions for power grid optimization and weather analytics for renewables. The Indian government, via NITI Aayog, released a National Strategy for AI and has set up centers of excellence, one focus area identified is energy, recognizing AI's potential in managing power systems. There are initiatives like **"AI for All"** and partnerships that aim to foster adoption in the energy sector. While there isn't a direct subsidy program for AI in energy, the government is investing in digitizing the grid, such as the RDSS (Revamped Distribution Sector Scheme) which includes installing smart meters and IT-OT integration in discoms. This essentially lays the data groundwork upon which AI algorithms can be applied. Utilities themselves are now investing in their digital capabilities; for example, Tata Power Delhi Distribution Ltd has set up an innovation center and is running AI pilots for network planning.

On the data centre side, the investment landscape is very active, with numerous announcements of new projects. Real estate developers, Indian conglomerates, and foreign investors are all pouring capital to build data centre parks. Notable players include Adani, Reliance Jio, Hiranandani Group, and international firms like NTT (Netmagic), ST Telemedia, Equinix. The hyperscalers typically lease from these operators or build their own campuses in key locations. Investment is also fueled by private equity and sovereign wealth funds attracted by the growth prospects, for instance, Blackstone and Brookfield have invested in Indian data centre ventures.

Energy integration is a notable theme in the investment landscape, many data centre operators are investing in their own captive renewable energy plants or entering into long-term PPAs to power facilities. This is partly because energy cost is a big chunk, often 40-50% of a data centre's operational expenses, and renewable PPAs can offer cost stability in addition to green branding. Some are also investing in on-site solutions like rooftop solar and large-scale battery storage to enhance reliability and use off-peak grid power efficiently. The government's viability gap funding scheme for battery storage could benefit data centres that want to deploy big battery systems for backup (instead of diesel gensets), a few data centre operators are exploring being early adopters of such clean backup power, which if proven, could become a standard.

2.4.4 Challenges & Opportunities

Theme	Challenges	Opportunities
Data Availability & System Integration	» Incomplete, poor-quality, or siloed grid and consumer data make AI training difficult.[81] » Legacy SCADA and field equipment lack IoT sensors, making integration of AI analytics challenging.	» AI can significantly improve renewable energy forecasting, cutting solar/wind forecast errors by 20–30%.[82] » India can develop exportable AI-based grid management solutions for other emerging markets.
Skills, Culture & Governance	» Shortage of data scientists with power sector domain knowledge; engineers often distrust algorithmic recommendations[83] » Lack of AI standards, explainability requirements, and cybersecurity readiness can delay regulatory approval.[84]	» Opportunity to build workforce capacity through industry–academia programs (AI + power systems) » Creating governance frameworks and standards can boost trust and accelerate AI.
Energy, Cooling & Infrastructure (Data Centres)	» 24/7 reliable power is a challenge; outages necessitate expensive diesel gensets or UPS, increasing costs and emissions[85] » Hot, humid climates raise cooling loads; water-intensive cooling systems face scarcity and permitting issues » Real-estate costs and permitting delays slow deployment.	» Growth of edge data centres colocated with renewable energy parks can lower costs and emissions[86] » AI-enabled dynamic cooling can reduce cooling energy by 30–40% (Google DeepMind case.[87] » Large data centres with battery storage can provide demand response and grid flexibility services.[87]
Regulatory & Financial Models	» Benefits of AI (loss reduction, efficiency) not always monetizable under current tariff frameworks, utilities may have no financial incentive. » No standardized grid codes for AI-driven control; regulatory uncertainty slows adoption	» Regulators can design incentive mechanisms (shared savings, performance-based regulation) to reward AI-driven efficiency gains. » National Digital Mission and AI policies can include funding for AI R&D in energy and sustainable data centre infrastructure.



3. Workforce Transformation: Skilling, Reskilling & Upskilling Imperatives

3.1. Current Workforce Landscape – Sectoral Employment Trends & Skill Levels

India's labor force is expanding, but much of it remains in low-skill roles. Agriculture still employs about 46% of workers (an increase from 45.8% a year prior), while manufacturing accounts for only ~11% and services 30%.[88] This heavy reliance on agriculture signals a need for economic diversification; in fact, the Economic Survey 2023–24 estimates India must create 78.5 lakh (7.85 million) non-farm jobs each year until 2030 to absorb the growing workforce.[89] Structural shifts toward industry and services are imperative for a more productive economy.

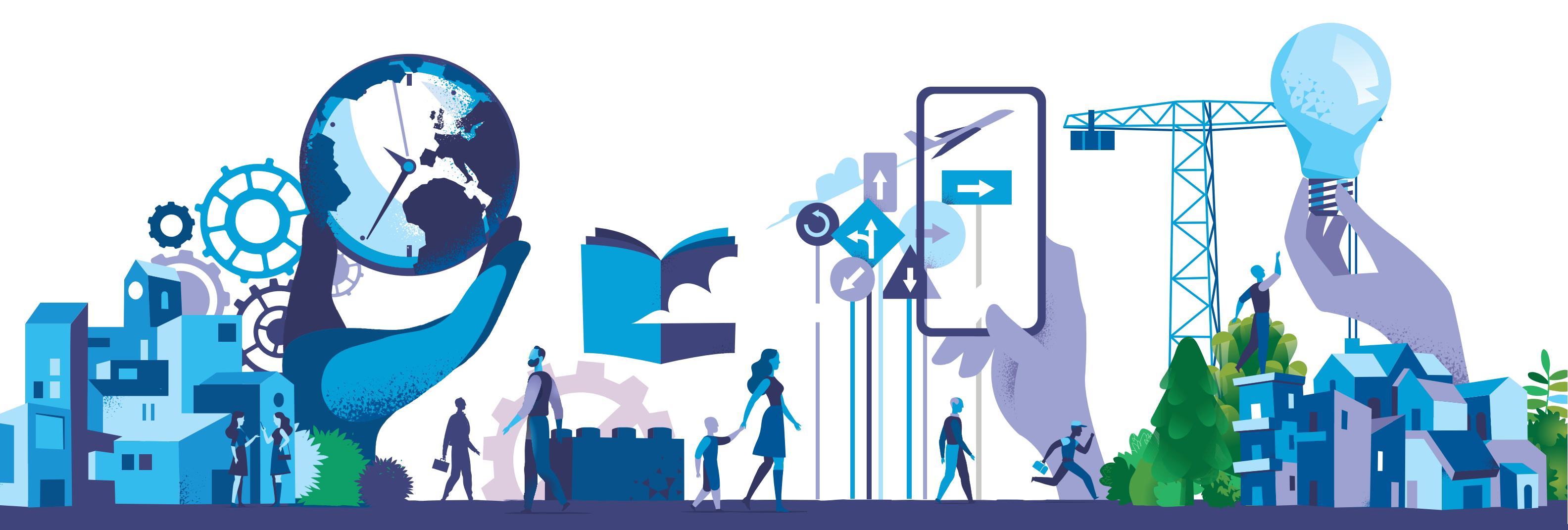
Skill levels in the current workforce remain a concern. Only about half of workers have education at secondary level or above, and a mere 4.1% of workforce aged 15–59 have received formal vocational training and 65.3% have no technical or vocational training at all. As a result, the vast majority of jobs are low-skill – an estimated 88% of India's workforce is engaged in low-competency occupations. There is also a significant mismatch between education and employment: over 53% of graduates (and 36% of postgraduates) are underemployed in roles below their qualifications. The overall employability of Indian graduates is only ~55% (as of 2025), highlighting persistent skill gaps despite recent improvements. This landscape underscores the urgent need for upskilling and reskilling at scale to leverage India's demographic dividend effectively.[90]

3.2. Skill Demand in Emerging Sectors: New-Age Industries & Their Requirements

3.2.1. Green Hydrogen (GH2)

Under the National Green Hydrogen Mission (NGHM), India has set a 2030 target of 5 MTPA green hydrogen production with ~₹8 lakh crore investments and 600,000 jobs potential, but hands-on competencies in electrolyser stack engineering, balance-of-plant (BoP), H_2 safety, compression/storage, and renewable-hybrid integration are nascent. Multiple studies and government briefs flag that >65% of new GH2 roles require up/re-skilling beyond traditional degrees, and ~78% of clean-energy employers struggle to find job-ready talent.

Role Overview	Critical skills (certs/ tools)	Availability 2025	Demand by 2030	Gap severity	Priority skilling moves (2025–30)	Real-world Programs
Electrolyser stack & systems engineers (PEM/ALK)	Stack design, PVD coatings, membrane/MEAs, BOP sizing, thermal/ water mgmt., IEC/ ISO H_2 safety	Low	High	Very high	6–9-month post-grad certificates with OEMs; simulation labs; OEM + IIT/NIT co-ops	QUB Hydrogen Energy Systems graduate certificate. UMass Lowell
H_2 process & safety (refineries, ammonia, steel)	HAZOP/HAZID, ATEX, PSM, PSA purification, leak detection, hazardous area classification	Low–Med	High	High	National H_2 safety academy; cross-training of refinery/chemical engineers	GH2 India, a multi-stakeholder platform, can enable partnerships and policy initiatives with universities like Deakin. Programs on microgrids, hydrogen systems, social licence, and fuel cell technologies can be adapted or co-delivered to build local capacity and accelerate workforce readiness.
Power & grid integration	RE-H_2 hybrid design, curtailment managements., VRE forecasting, PPA/ contracts, SCADA	Low	High	High	Utilities + EPC micro-credentials; system operator apprenticeships	UMass Lowell Grid-Connected Solar Electric Systems course.
Compression, storage & logistics	HIC metallurgy, composite cylinders, LH_2 handling, pipeline codes (ASME/EN)	Very Low	Med–High	Very high	Vendor-led hands-on training; standards & inspection pathways	N/A



Role Overview	Critical skills (certs/ tools)	Availability 2025	Demand by 2030	Gap severity	Priority skilling moves (2025–30)	Real-world Programs
O&M technicians	Clean-in-place, stack refurbishment, water treatment, CM/PM, digital twins	Low	High	High	OEM-approved Level-3/4 quals under NSQF; mobile training units	Skill Council for Green Jobs (SCGJ) India offers NSQF Level 4 Green Hydrogen Plant Technician and Level 3 Green Hydrogen Plant Junior Technician programs via PMKVY 4.0.
Non-technical (project, HSE, supply chain)	EPC project control, risk, ESG/HSE, procurement, QA/QC, financing	Med	High	Med–High	PMKVY 4.0 green-tech tracks; HSE & ESG micro-badges	Green Jobs training programs like Bridges to Green Jobs also focus on essential non-technical skills.

Sources: NGHM/GOI overview and targets; GH2 job potential; GH2 skill-gap/qualification development and employer hiring frictions.

3.2.2 Waste-to-Energy (WtE) & Bio-CNG/CBG

The push for sustainability is driving growth in waste management and waste-to-energy (WtE) projects. Converting waste to energy requires technicians skilled in biogas generation, incineration plant operation, and municipal waste processing. Major job creation is expected in the waste management sector as part of India's green economy expansion, alongside renewables and other green industries.[91] To support this, the Skill Council for Green Jobs (SCGJ) has developed qualifications for waste management roles,[92] ensuring standardized training in areas like waste treatment, recycling, and bioenergy. Building a pipeline of WtE plant operators, maintenance engineers, and environmental specialists will be crucial as India taps into its large untapped WtE potential. Recent evidence provides FTE norms for CBG construction/operations and underscores the need for operator and safety training at municipal and agri feedstock sites.

Roles	Critical skills	Availability 2025	Demand by 2030	Gap severity	Priority skilling moves	Real-world Programs & Context from Research
AD/CBG process engineers & operators	Feedstock pre-treatment, digester control, H_2S removal, PSA/membrane upgradation, biosafety	Low	High	High	SCGJ QPs + OEM plant residencies; city-utility operator academies	SCGJ is a key body in India for developing vocational qualifications in this space.

Roles	Critical skills	Availability 2025	Demand by 2030	Gap severity	Priority skilling moves	Real-world Programs & Context from Research
Thermal WtE (incineration/ gasification/ pyrolysis)	Boiler/turbine ops, flue-gas cleanup (SCR/ FGD), slag/ash handling, LOTO, stack testing	Low–Med	Med–High (urban clusters)	High	MNRE-accredited shift-operator programs; emissions compliance training	MNRE, India provides financial assistance to projects contingent on performance (e.g., Plant Load Factor), creating a policy-driven incentive for high-quality training.
I&C, electrical & mechanical maintenance	PLC/DCS, VFDs, vibration, pumps, blower maintenance, predictive analytics	Med	Med-High	Med–High	Multi-skilling kits via ITIs/ polytechnics; OEM field schools	Cross-industry certifications like CMRT and IMM are crucial for validating core technical skills transferable across heavy industries.
Environmental compliance & HSE	CEMS, waste audit, SOPs, ISO 14001/45001	Med	High	Med	SCGJ/PCB joint modules; inspector upskilling	OSHA 10 & 30 safety training is a foundational, cross-industry requirement.
Supply chain & municipal ops	Segregation logistics, waste audits, contracting, SLAs	Med	High	Med	ULB-SCGJ programs; PPP project mgmt badges	Green Jobs programs in the U.S. highlight the importance of logistical and project management skills.
Non-technical (PPP/finance, community)	PPP structuring, tariffs, carbon credits, stakeholder engagement	Low–Med	Med	Med	PPP finance micro-credentials; carbon/REC literacy	N/A

Sources: MNRE WtE programme and status; CBG/SATAT FTE norms; SCGJ green jobs qualifications; MNRE progress dashboards and updated guidelines.

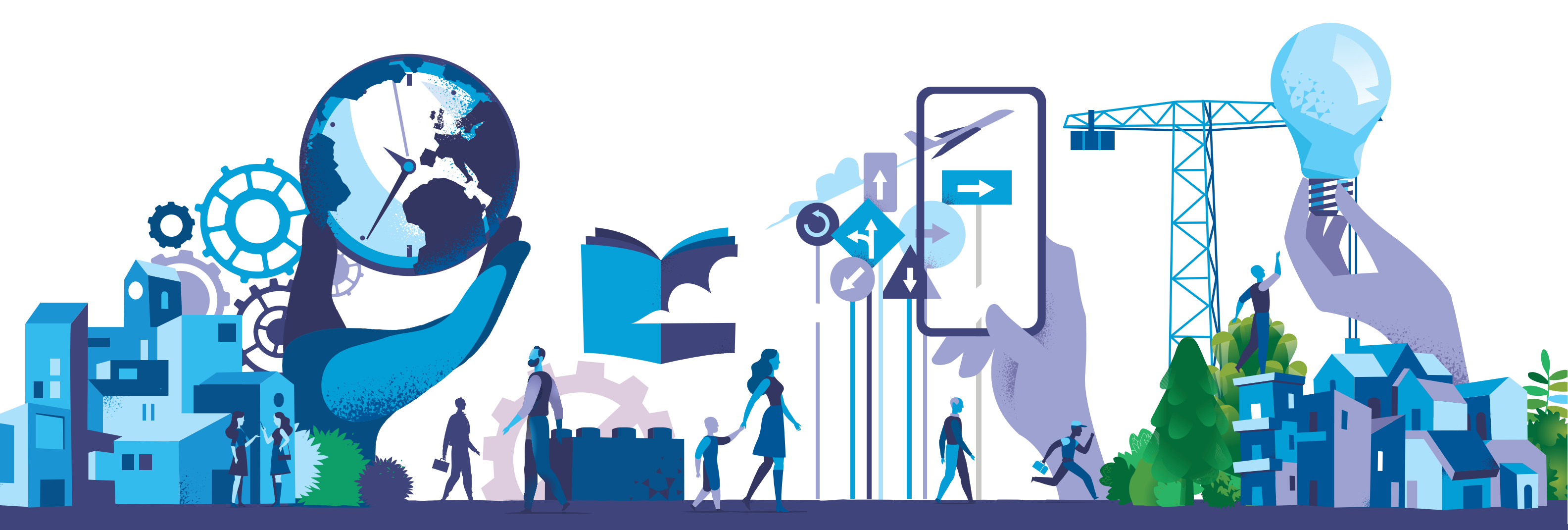
3.2.3 Semiconductors

India's ambitions in semiconductor manufacturing (through the India Semiconductor Mission) have spotlighted a serious skills shortage in this high-tech sector. The industry is projected to grow exponentially; market size from $26 billion in 2022 to $272 billion by 2032,[93] but talent supply isn't keeping up. Study estimates a shortage of 250,000–300,000 skilled semiconductor professionals by 2027.[94] Roles in chip fabrication, VLSI design, validation, and semiconductor equipment maintenance demand advanced engineering skills and practical experience. Currently, India has a strong semiconductor design workforce about 100,000 VLSI design engineers,[95] ~20% of the global design talent),[96] but experience in actual chip fabrication and process engineering is limited. Companies report they can only fill roughly 60% of skilled job openings in semicon/electronics manufacturing, with the gap especially acute for fresh graduates.[97] This sector needs highly specialized engineers for lithography, clean-room operations, packaging, etc., requiring both curriculum overhaul and hands-on training opportunities to produce fab-ready talent.

Segment	Signature roles	Availability 2025	Demand by 2030	Gap severity	Priority skilling moves	Real-world Programs & Context from Research
EDA/IP	HDL, verification, PDK enablement, sign-off	Med–High	High	Med	University IP tracks; foundry PDK enablement residencies	N/A
Design (fabless/IDM design)	RTL→GDSII, DFT/DFM, AMS, PPA, safety/IP	High	Very High	Med	Expand taped-out capstone projects; silicon-proven design studios	N/A
Foundry/Fab (FEOL/BEOL)	Process integration, litho/etch/CVD/PVD/CMP, yield/defect, metrology, cleanroom ops	Very Low	High	Very high	OEM/toolmaker academies; 12–18-month apprenticeships at partner fabs	The Intel/Maricopa Community College partnership offers a Semiconductor Technician Quick Start program. The European consortium imec offers dual learning programs for cleanroom staff.

Segment	Signature roles	Availability 2025	Demand by 2030	Gap severity	Priority skilling moves	Real-world Programs & Context from Research
OSAT/ATMP	Bumping, FOWLP, 2.5D/3D, reliability, substrate tech, test	Low	High	High	Multi-customer ATMP campuses; substrate/test engineering schools	The National Semiconductor Technology Center (NSTC) is a public-private consortium aimed at building and sustaining the semiconductor workforce ecosystem.
Equipment (field service/ applications)	Tool install/qual, PM/CM, recipe dev, spares logistics	Low	Med–High	High	Vendor-certified field-service pathways; spares/ logistics training	SEMI University provides global, industry-specific curriculum and certifications.
Materials	Wafers, gases, slurry, photoresists/ EUV, masks	Very Low	Med	High	JVs + chem-process micro-credentials; QC/ metrology labs	N/A
R&D/Institutes	PDKs, pilot lines, reliability labs, consortia	Low	Med	Med–High	imec-style programs; open fabs for academia	Imec offers universities affordable access to industrial-grade design tools and prototyping capabilities through the EUROPRACTICE consortium.

Sources: Lam–IISc Semiverse/SEMulator3D scale-up.



3.2.4 AI-Enabled Energy Systems & Data Centres

The energy sector is rapidly adopting digital technologies from smart grids and AI-driven analytics to IoT sensors for grid management. These "AI-enabled" energy systems demand a new breed of digital specialists who understand both power engineering and data science. Utilities require professionals skilled in AI/ML, data analysis, IoT, and cybersecurity to implement smart demand response, predictive maintenance of grid infrastructure, renewable energy forecasting, and energy management systems.[98] However, a talent gap looms here as well: in a global survey, 89% of energy sector employers cited skill gaps as the main barrier to adopting digital technologies in power systems. The result is fierce competition for data engineers, AI experts, and automation specialists who can drive the digital transformation of energy. Hybrid roles combining energy domain knowledge with digital skills (e.g. "energy data analysts", smart grid software engineers) are projected to see a 4–6x capital increase in demand in the coming years[99] .Investing in training programs for AI, IoT, and software skills tailored to energy applications will be critical to operate next-generation AI-enabled energy systems safely and efficiently.

India's data-centre build-out is steep capacity projected to ~4.5–5.0 GW by 2030 with $20–22 bn capex. Yet AI-energy hybrid talent (power + data) and critical-environment technicians are scarce. Operational staffing is lean (BCG: ~50 FTE per 100 MW), so the real shortfall is in high-skill roles (MLOps, grid analytics, cyber, cooling/power engineering).[100]

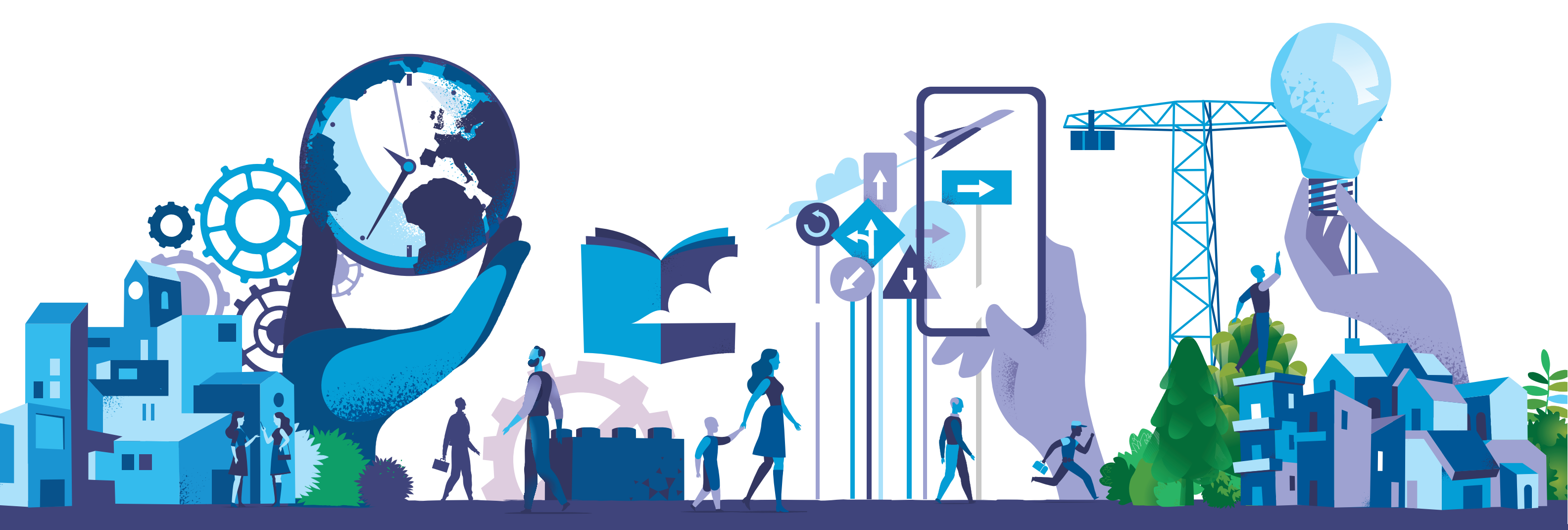
Role family	Critical skills	Availability 2025	Demand by 2030	Gap severity	Priority skilling moves	Real-world Programs & Context from Research
AI for grid & assets (DS/ML engineers, energy data analysts)	Forecasting, state estimation, anomaly/predictive maintenance, PyTorch, on-prem/edge	Med	High	Med–High	Utility–ISGF micro-certs; sandboxes with real-world SCADA/AMI data	AI is used for predictive maintenance and load forecasting in grid systems.
MLOps & model risk	Model lifecycle assessment, monitoring, drift, auditability, safety	Low–Med	High	High	Power-sector MLOps diplomas; regulator-aligned governance modules	AI-powered tools are used to analyze skill gaps and recommend training, creating a self-referential feedback loop.
Critical facility technicians (DC)	HV/LV, UPS/gensets, cooling (chillers/liquid), BMS/DCIM, Uptime/TIA standards	Med	High	Med–High	Vendor-neutral DC operations academy; Uptime-style certifications	Kaushalya Skill University offers a Data Centre Technician course (NSQF Level 4). HPE offers training for EPI

Role family	Critical skills	Availability 2025	Demand by 2030	Gap severity	Priority skilling moves	Real-world Programs & Context from Research
Network & security	SDN, zero trust, SOC, OT/ICS security	Low–Med	High	High	Joint programs with CERT-IN, cloud majors	AI can enhance cybersecurity preparedness by automating vulnerability assessments and detecting network anomalies.
Siting, power procurement & RE integration	Open access/GPAs, storage hybrids, demand response	Low	Med–High	High	RE-PPA & storage micro-credentials; utility rotations	AI can be used to optimize utility investment decisions and analyze land use restrictions for siting.
Non-technical (ESG/ compliance, project controls)	Water/power PUE/WUE, ESG reporting (ISSB), capex control	Med	High	Med	ESG analyst pathways; construction PM bootcamps	Data center technicians require non-technical skills like clear communication and systemic thinking.

Sources: IBM energy/utility AI adoption; IEA "Energy & AI" (power-system digital skills outlook); Colliers & ET Energy data-centre build-out to ~5 GW by 2030; BCG staffing benchmarks.

3.3 Bridging the Gap

The rise of these new industries has exposed a yawning gap between skill supply and demand. India faces shortages of qualified technicians, engineers and digital specialists across sectors – from renewable



energy project engineers and hydrogen experts to chip fabrication technicians and AI analysts. For instance, the renewable energy sector could create 1.7 million jobs by 2030 but faces an estimated skill gap of 1.2 million workers[101] to fill those roles. Similarly, the semiconductor industry may be a quarter-million workers short of requirements by 2027.[102] These shortages span all levels: skilled tradespeople and technicians (e.g. solar panel installers, waste plant operators), engineers (electrical, chemical, mechanical with new specializations), and digital experts (data scientists, automation engineers for Industry 4.0).

Bridging this gap will require an aggressive, multi-pronged effort in skilling, reskilling, and upskilling. First, the capacity and reach of training programs must expand significantly – especially since currently only ~4% of the workforce has formal skill training.[102] Existing workers will need continuous upskilling to keep pace with technological change, while new workforce entrants need job-ready skills rather than only theoretical education. Stakeholders are beginning to respond employers are ramping up in-house training (e.g. technical bootcamps in semiconductor firms and reports recommend systematic skill data collection to pinpoint evolving industry needs). Crucially, stronger linkages between industry and education are needed so that training aligns with market demand. By bolstering vocational education, promoting apprenticeships, and updating curricula to include emerging skills (AI, robotics, green tech), India can start to close the talent gap. The following sections discuss some of the major national initiatives and collaborative strategies aimed at bridging these workforce skill gaps.

3.4 Flagship National Programs

To tackle the skilling challenge, India has launched several flagship programs and policy initiatives under the broader "Skill India" mission. Key among them are:

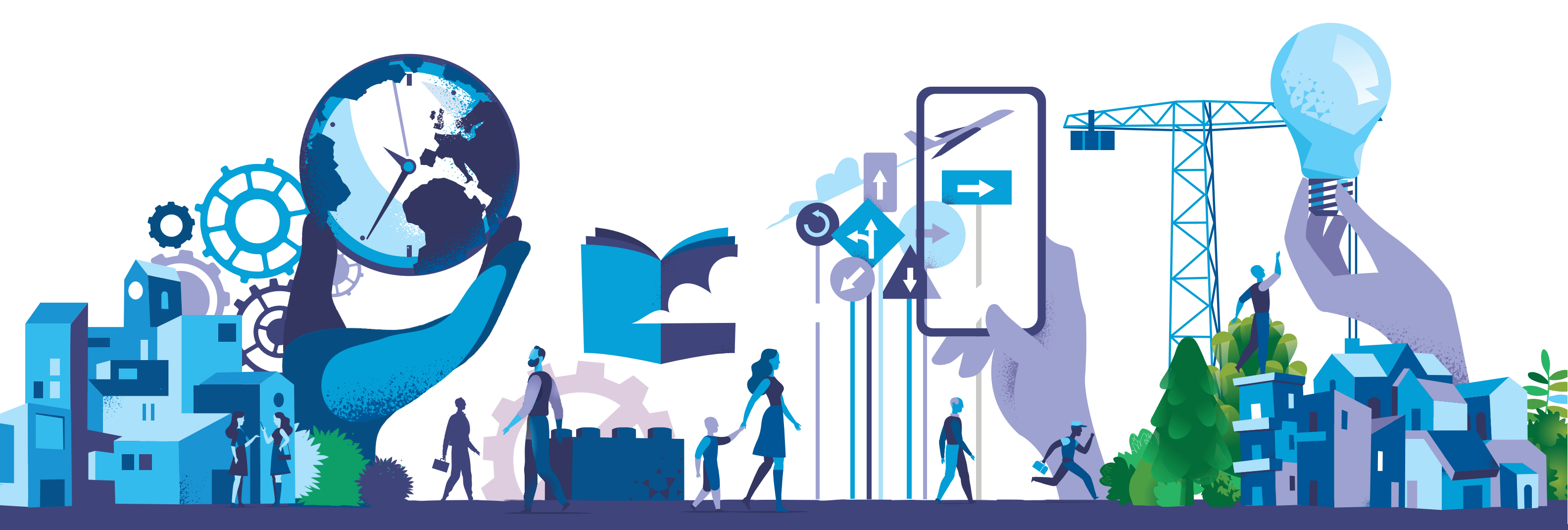
» Skill India & National Skill Development Mission (NSDM) – Launched in 2015, the Skill India campaign and NSDM set an ambitious target to train 30 crore (300 million) people by 2022 in market-relevant skills.[103] While that target has not yet been fully met, the initiative established a comprehensive framework for skill development from national to district levels. It led to the creation of the Ministry of Skill Development and Entrepreneurship (MSDE) and agencies like the National Skill Development Corporation (NSDC) to fund and coordinate skill training programs. Annual budgets for skill development have steadily increased (₹6,100 crore in 2025-26, up from ₹2,999 crore in 2022-23, reflecting the government's prioritization of building a skilled workforce.

» Pradhan Mantri Kaushal Vikas Yojana (PMKVY) – This is the flagship skill-training scheme under Skill India. PMKVY, launched in 2015, provides free short-term training courses and certification incentives to youth across the country. After an initial pilot phase, PMKVY 2.0 (2016–2020) scaled up with a target of training 10 million (1 crore) people, and indeed over 11 million candidates were trained under PMKVY 2.0. The latest PMKVY 4.0 (announced in 2023) shifts focus to emerging technologies – offering courses in areas like artificial intelligence, robotics, mechatronics, and drones. The scheme operates through accredited training centers nationwide, offering Short-Term Training (200–500 hour courses for school dropouts and unemployed youth) as well as Recognition of Prior Learning (short bridge courses to certify existing skills).

» National Apprenticeship Promotion Scheme (NAPS) – Recognizing the importance of on-the-job training, NAPS was launched in 2016 to incentivize employers to engage apprentices under the Apprentices Act. The government shares a portion of stipends and training costs to encourage companies to take on apprentices. NAPS was revamped as NAPS 2.0 in 2022 with features like Direct Benefit Transfer of stipend support (₹1,500 per month per apprentice directly to their bank accounts). As of September 2024, NAPS has facilitated 36.6 lakh (3.66 million) apprentice engagements, with 18.5 lakh completing training and 5.6 lakh certified. Top sectors for apprentices include automotive, IT, electronics, retail, and manufacturing. Despite this progress, apprentices still form only about 2% of India's workforce, far below levels in countries with strong apprenticeship cultures. Expanding industry participation in NAPS and improving retention (drop-out rates have risen to ~35% in recent years) are ongoing priorities to make apprenticeship a mainstream route for skill development.

» Sector Skill Councils (SSCs)[104] – As part of the NSDC ecosystem, India has established over 30 Sector Skill Councils led by industry bodies to develop industry-relevant skills standards and qualifications. For example, the Skill Council for Green Jobs (SCGJ) was set up in 2015 to focus on skills for renewable energy, environmental services, and sustainability sectors. SSCs create National Occupational Standards and certification frameworks to ensure training quality. As of June 2024, SCGJ has developed 77 nationally-approved qualifications spanning renewable energy, waste management, clean cooking, sustainable agriculture, etc. Through a network of 900+ training partners, over 560,000 candidates have been trained in green job skills under SCGJ programs. Similar councils exist for other industries – e.g. Automotive Skills Development Council, Electronics SSC, IT/ITeS SSC – each aligning vocational training with the evolving needs of their sector. These councils often work closely with companies to update curricula and certify trainees to be "job-ready" for their respective industries.

» Other Initiatives – The government continues to launch targeted skilling programs for specific demographics and trades. The Jan Shikshan Sansthans (JSS) scheme, for instance, provides vocational training to non-literate and underprivileged adults in rural and semi-urban areas, with a focus on women and marginalized groups. Another recent program is PM Vishwakarma, launched in 2023 to upskill traditional artisans and craftsmen (like carpenters, blacksmiths, weavers, etc.) and integrate them into modern value chains. PM Vishwakarma offers skills training along with toolkits, stipend support, and access to easy credit for artisans to improve their livelihoods. Likewise, the National Green Hydrogen Mission (NGHM) includes a skill-development component to train workforce for the nascent green hydrogen industry.[105] These programs, along with the major schemes like PMKVY and NAPS, form a multi-faceted approach by the government to boost skills across the spectrum – from high-tech sectors to traditional crafts – thereby transforming the workforce for future needs.



3.5 Role of Industry & Academia Partnerships

Bridging the skill gap is not the government's job alone, collaboration between industry and educational institutions is pivotal to create a future-ready workforce. Closer industry–academia partnerships are enabling more practical, market-aligned training through several approaches:

Partnership approach	Core objective	India examples	How it works (roles)	What to institutionalise next (2025–2030)	Outcomes / scale (with sources)
Co-designed curricula	Align degrees with industry demand in semiconductors, AI, hydrogen; graduate "project-ready" talent.	» AMD India engineers co-creating chip-design/verification & hardware-security courses with colleges » Semicon India Future Skills Committee set up to drive curriculum redesign in semiconductors » Green hydrogen: experts call for PPP-led curricula to build electrolysis, H_2 safety & BoP capabilities	Industry: maps competencies, donates PDK/ tools, mentors capstones. Academia: embeds AI-chip/ IoT/power-electronics tracks, credits labs. Govt/SSCs: fast-track approvals; NSQF/credit mapping.	» Make co-created tracks mandatory in public engineering programs for target sectors. » Fund shared labs (PDK benches, H_2 safety rigs). » Annual sectoral skills-gap audit to refresh curricula.	Industry-led syllabi and design studios expanding across IITs/ NITs; early H_2 modules in pilot clusters (illustrative partnerships growing across 2024–25)[106]
Apprenticeship & work-based learning	Close the "experience gap" with line-time; blend theory with paid rotations.	» TeamLease Degree Apprenticeship (dual-learning: degree + paid apprenticeship) » NAPS/NEP: on-the-job training with stipend support to apprentices » Lam Research–ISM–IISc 'Semiverse Solutions' to upskill ~60,000 engineers over 10 years via virtual fab/tooling	Industry: structured rotations; mentors; assessment input. Academia: credit-bearing apprenticeships/ sandwich semesters. Govt: stipend support; QA of apprenticeships.	» Target 25–30% of engineering seats as credit-linked apprenticeships by 2028. » • Stipend top-ups for fab techs, H_2 O&M, and DC critical-environment techs. » Train-the-trainer clauses in all incentive MoUs.	Growing degree-apprentice cohorts; Semiverse expanded to 20 Indian universities (2024) as part of 10-year plan[107]

Partnership approach	Core objective	India examples	How it works (roles)	What to institutionalise next (2025–2030)	Outcomes / scale (with sources)
Micro-credentialing & continuous learning	Rapid, stackable upskilling for students & working professionals tied to industry certificates.	» Leaders' view: 98% of higher-ed leaders back micro-credentials; credit-bearing share expected to reach 94% in 5 years (NCrF-aligned) » NSDC eSkill India: hundreds of NSQF-aligned micro-courses for employability/ green jobs (National Skill Development Corporation)	Industry/ platforms: co-create short courses; verifiable badges. Academia: map to credits via NCrF; blended/ on-line delivery. Employers: use badges for hiring & progression.	» Mandate a 6–12 credit micro-credential spine in all STEM degrees. » Recognise employer badges for PG lateral entry.	Micro-credentials becoming mainstream in AI/data/ cloud/green jobs; HEIs formalising credit policies (2024–25 trajectory)[108]

4. Case Studies & International Best Practices

The transition to a green economy is a global endeavor, and India both contributes to and learns from international experiences. In this chapter, we highlight global benchmarks that provide perspective on India's progress, and showcase case studies – including Indian pilot projects and success stories – that offer valuable lessons. These examples illustrate what is achievable and how strategic approaches can yield impactful results, serving as inspiration for scaling up.

4.1 Global Benchmarks and Comparisons

4.1.1 Green Hydrogen: Lessons from EU Hydrogen Valleys

Global Benchmark – EU Hydrogen Valleys

The European Union's Hydrogen Valleys initiative, supported by the Clean Hydrogen Partnership, integrates hydrogen production, storage, distribution, and end-use across Mobility (buses, trucks, fleets), and power sectors. With over 30 Hydrogen Valleys globally and €30 billion in investments, the initiative emphasizes regional ecosystems that create jobs, decarbonize local economies, and foster innovation.[109]

Indian Context:

India's National Green Hydrogen Mission aims to produce 5 MMT of green hydrogen annually by 2030. However, workforce readiness remains a challenge. The Ministry of Skill Development and Entrepreneurship (MSDE) is yet to roll out hydrogen-specific training at scale, though pilot skilling programs.

4.1.2 Semiconductor Manufacturing: South Korea's Talent Pipeline

Global Benchmark – South Korea

South Korea's Ministry of Trade, Industry and Energy (MOTIE) has launched a 10-year semiconductor workforce strategy, aiming to train 150,000 engineers by 2030.[110] The plan includes:

» University-industry collaboration for curriculum design.

» Government-funded chip design labs.

» Incentives for companies to offer apprenticeships.

Indian Context:

India's Semicon India Programme, led by Ministry of Electronics and Information Technology (MeitY), includes a Design Linked Incentive (DLI) scheme and the establishment of Indian Institutes of Semiconductor Manufacturing. The Tata Indian Institute of Skills (TIIS) in Mumbai and Ahmedabad offers courses in industrial automation, robotics, and chip design.[111]

4.1.3 Waste-to-Energy: Circular Economy Workforce Models

Global Benchmark – EU & Japan

Germany and the EU have integrated Waste-to-Energy (WtE) into their broader circular economy and just transition frameworks. The European Commission emphasizes reskilling and upskilling in regions transitioning away from coal and fossil fuels, including training in WtE operations, emissions monitoring, and digital plant management. These efforts are part of the EU Just Transition Mechanism, which supports workforce development in clean energy sectors.

Japan, through its Ministry of the Environment, runs regional decarbonization seminars and training programs for local governments and plant operators. These include modules on:

- Waste segregation and anaerobic digestion
- Bioenergy systems
- Emissions monitoring and digital tools for plant optimization

The programs aim to build "regional core human resources" to lead local decarbonization projects, including WtE plants.[112]

Indian Context

India has over 850 MW of installed WtE capacity, but workforce development remains fragmented. The Ministry of Environment, Forest and Climate Change (MoEFCC) and the National Mission for a Green India have initiated pilot training programs for:

- Waste segregation and composting
- Bio-methanation and RDF (Refuse-Derived Fuel) handling
- Emissions control and plant safety

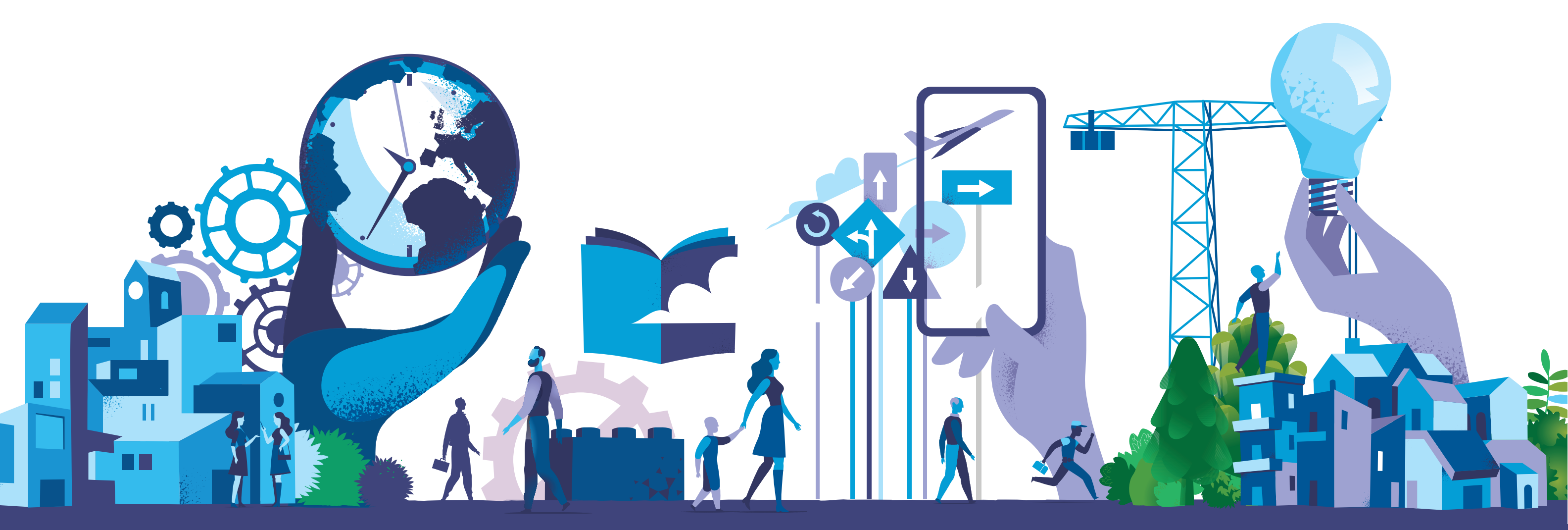
The Waste Minimisation Circle (WMC) under MoEFCC has also supported MSMEs in adopting cleaner production techniques.[113]

4.1.4 AI & Data Centres: Skilling for the Digital Backbone

Global Benchmark – United States & Singapore

The U.S. and Singapore have launched AI skilling frameworks[114] that integrate:

- AI literacy from school level.
- Micro-credentials for cloud computing, cybersecurity, and data analytics.
- Public-private partnerships with tech giants for curriculum and internships.



Indian Context:

India's AI Mission, under MeitY, is establishing Centres of Excellence and a National Data Platform. The SOAR (Skilling for AI Readiness) program by MSDE aims to embed AI training from Class 6 onwards, with pathways to advanced careers in data science and cloud infrastructure.

4.2 Lessons for Scalability in India

Sector	Key Takeaways for India
Green Hydrogen	» Integrated Value Chains: Projects that combine production, transport, and end-use are more viable. » Public-Private Partnerships: Over 50% of EU Hydrogen Valleys are led by private sector consortia. » Policy Support: EU provides regulatory clarity, permitting frameworks, and funding mechanisms. » Leveraging renewables – India's solar and wind potential gives it a cost advantage for green hydrogen production, making export-oriented Hydrogen Valleys feasible.
Semiconductor Manufacturing	» Long-Term Workforce Planning: Adopt a decade-long national skilling strategy aligned with Semicon India Programme. » University–Industry Collaboration: MoUs between engineering institutes and chip manufacturers. » Government-Funded Infrastructure: Scale up chip design labs and mini-fabs under PLI and DLI schemes. » Apprenticeship Incentives: Use NAPS to promote hands-on learning in fabs. » Global Exposure Programs: Sponsor international fellowships for advanced chip design and fabrication.
Waste-to-Energy	» Localized Training Hubs: Establish state-level WtE training centers with ULBs and Smart Cities. » Digital Monitoring Skills: Integrate real-time emissions tracking into ITI and polytechnic curricula. » Municipal-Industry Collaboration: Promote PPP models with skilling mandates. » Cross-Sectoral Curriculum: Include environmental compliance, circular economy, and energy recovery in training.
AI & Data Centres	» Start Early with AI Literacy: Expand SOAR to include AI fundamentals from Class 6 onwards » Micro-Credentials and Modular Learning: Use platforms like eSkill India and Skill India Digital. » Public–Private Partnerships: Collaborate with tech giants under IndiaAI Mission. » AI for All – Inclusive Access: Use CSCs and state missions for community-based skilling. » Data Centre Workforce Specialization: Train in cooling systems, energy efficiency, and server maintenance.

5. Strategic Roadmap

India's next decade of energy transition is a once-in-a-generation opportunity to shape the nation's future and cement its place as a global clean energy leader. Technologies are proven and capital is increasingly abundant, but the defining factor will be India's ability to build and mobilize the talent needed to deliver at scale. The skills gap is no longer a narrow education concern, it is a strategic imperative that will decide whether India can lead the world in green hydrogen, waste-to-energy, semiconductors, and AI-enabled digital infrastructure. Closing this gap is not just about filling jobs; it is about creating a globally competitive workforce that drives innovation, accelerates deployment, and attracts investment. This roadmap serves as the basis for focussed and indepth discussion on various aspects for a coordinated efforts to align human capital development with national technology ambitions, guided by three core principles and a sector-by-sector plan to convert vision into action.

5.1 Guiding Principles for a Future-Ready Workforce

The roadmap rests on three core principles that serve as design rules for workforce planning:

1. Human resource development integration

Every new technology needs adequately skilled human resources for its adoption/adaptation and innovation to reap full benefits of the technology. The human resource strategy for producing job-ready professionals who will design, install, operate and maintain the new systems should, therefore, be an essential component of national initiatives in new and emerging technologies. Explicit capital allocation for human resource development must be made in strategic initiatives.

2. Certification of skills

Certification programs and qualifications Packs should be developed in new and emerging technologies to provide confidence to industry and allow skilled personnel to move easily across projects and geographies, improving utilisation of trained talent and reducing hiring bottlenecks.

3. Hands-On Training

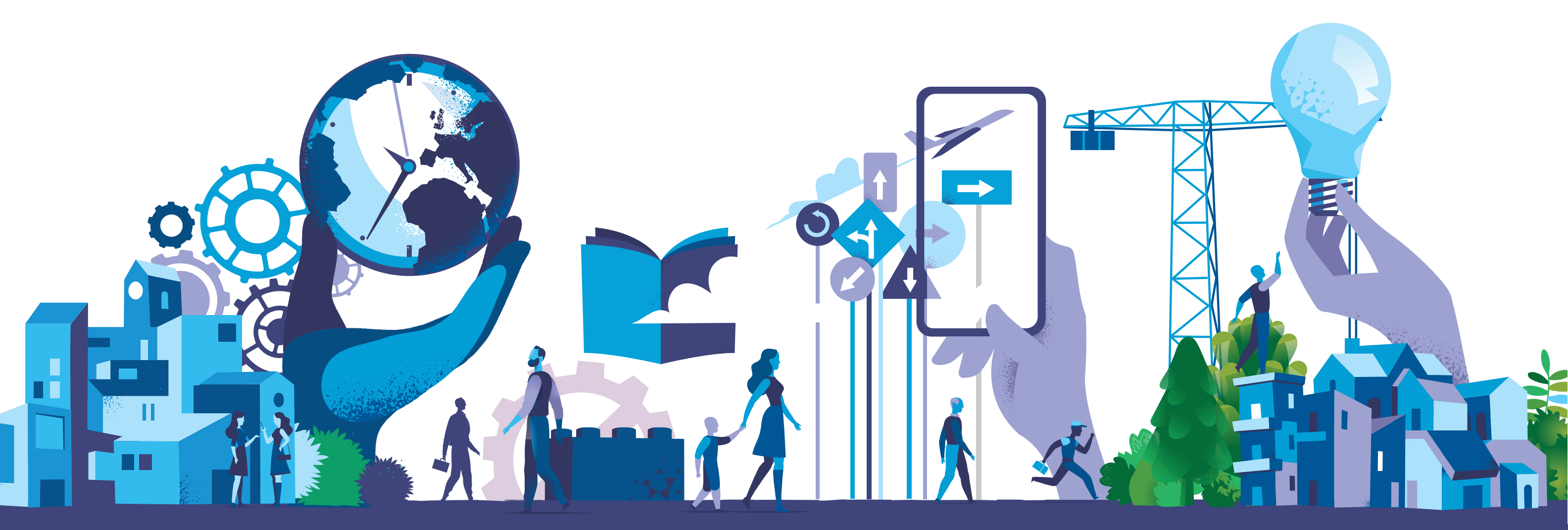
Hands-on experience in plants, laboratories, and simulators would provide the practical exposure to the workforce before getting into real-world conditions of the industry in new and emerging technologies.

5.2 Integrated Roadmap for Priority Sectors

An integrated roadmap for the four sectors covering the suggested actions, skill types, practice facilities, and mechanisms for certification and demand aggregation is presented below.

New and Emerging Technology	Action	Skill Type	Facilities and Partners	Certification and Demand Aggregation
Green Hydrogen	Industry partners co-fund OEM-embedded stack and R&D laboratories, publish three-year hiring plans, and adopt recognised certifications. Academia embeds hydrogen safety and BoP modules in the course curriculum and enables faculty sabbaticals in operating plants.	Stack and BoP engineers, hydrogen safety specialists, logistics professionals, multi-skilled O&M technicians.	Electrolyser OEMs, EPC contractors, safety vendors, IIT and NIT laboratories,	Cluster-level memoranda of understanding for workforce intake, NGHM jobs dashboard, NSQF Level 4 and 5 certifications, micro-credentials in HAZOP and process safety management.
Waste-to-Energy / Bio-CBG	Industry opens plants for apprenticeships, co-runs training schools with OEMs, and standardises operating procedures. Academia develops training programs with Urban local bodies, introduces multi-skilling opportunities, and provides CEMS and HSE assessorA training.	AD and CBG operators, flue-gas and boiler technicians, instrumentation and control specialists, emissions and compliance assessors.	Urban local body PPPs and private operators, MNRE WtE demonstration labs, EU and Japan twinning sites for operator exchange.	City-level PPP tenders with certification requirements, qualification packs, and micro-credentials for emissions monitoring and compliance.

New and Emerging Technology	Action	Skill Type	Facilities and Partners	Certification and Demand Aggregation
Semiconductors	Industry develops initiatives such as the Semiverse, establishes vendor tool academies for installation, qualification, and preventive maintenance, and seeds ATMP substrate and testing schools. Academia integrates virtual fab and cleanroom simulators, creates ATMP labs with test benches, and introduces taped-out capstone projects.	Fab operators, equipment and yield engineers, ATMP packaging and testing professionals.	Global vendor laboratories (Lam, Applied, KLA, TEL), Tata-PSMC Dholera, Micron Sanand, imec-style residencies.	Periodic role forecasts published by the ISM cluster, vendor-specific training certifications, and structured career ladders endorsed by the industry.
AI and Data Centres	Industry establishes critical-environment schools with hyperscalers, launches MLOps residencies with utilities, and conducts joint cybersecurity exercises. Academia sets up utility-AI programs with SCADA and AMI sandboxes, develops power and cooling laboratories, and delivers OT and ICS security modules.	Data centre technicians, grid-AI and MLOps specialists, OT and ICS cybersecurity professionals.	Data centre operators, cloud providers, CERT-In, state data centre parks, academic-industry sandbox laboratories.	Publish staffing norms per megawatt, committed intake windows with higher education institutions, National Credit Framework stackable micro-credentials, internationally recognised data centre certifications.



5.3 System-Level Enablers

To make the roadmap effective, four enabling mechanisms are essential:

» **Workforce Mandates:** Every mission should include explicit role counts, apprenticeship and training capacity targets to ensure that workforce planning forms an integral part.

» **Outcome-Linked Funding:** Funding for capacity building should be tied to certified completions and verified placement rates rather than enrolment numbers, driving accountability and quality outcomes.

» **National Skills Dashboard:** A dashboard should periodically portray the number of skilled workers needed, trained, and placed, broken down by cluster and technology with a view to make policy adjustments and capacity planning.

» **Faculty and Trainer Development:** Faculty sabbaticals and industry residencies should become standard practice, ensuring that educators remain up to date with the latest operational practices and technologies.

5.4 Execution and Feedback Loop

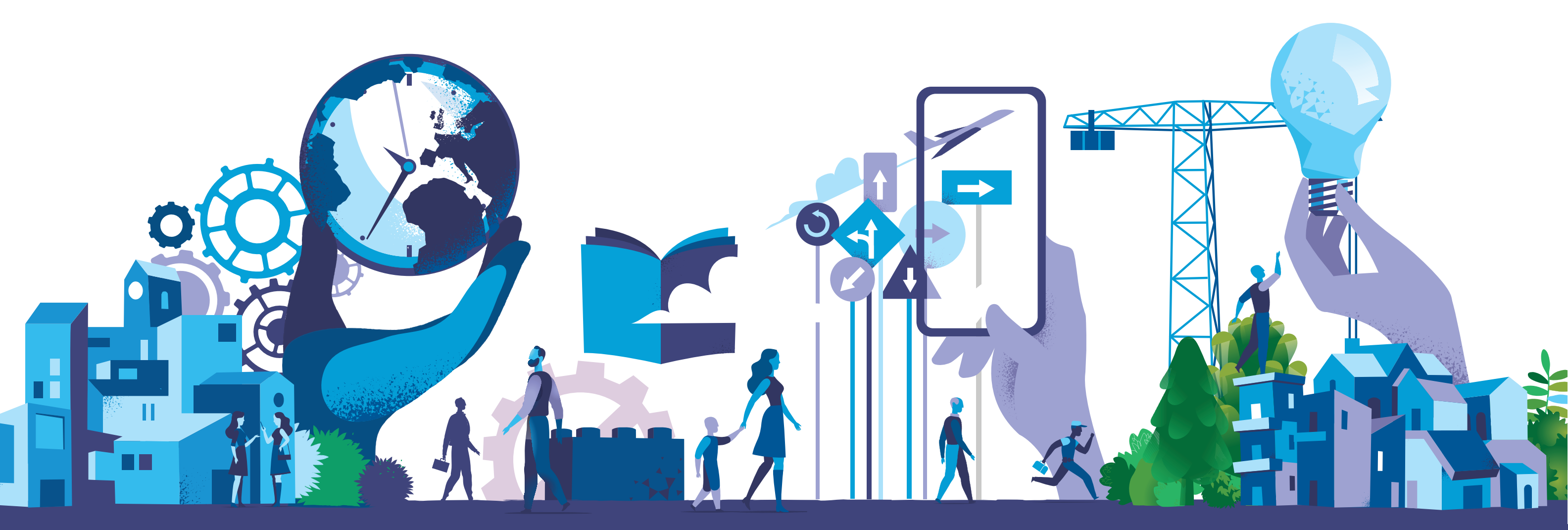
This roadmap is designed as a dynamic, a broad framework rather than a one-time plan. It must run on an annual cycle of forecasting, training, and measurement. Industry associations should publish future workforce demand signals, academic and training partners must expand seat capacity to meet those forecasts, and a national skills dashboard should track outcomes to inform timely course corrections.

This continuous cycle ensures that human capital development evolves in step with technology deployment. By aligning talent creation with capital investment, India can transform ambitious infrastructure plans into operational successes. The result is measurable impact: certified training capacity matched to demand, three-fourth job placements within six months of training, a workforce where certified professionals dominate hiring pipelines, and improved productivity and reliability across assets.

Ultimately, this approach allows India not only to deploy advanced technologies but to operate them with confidence, export its expertise globally, and convert its demographic dividend into a sustained competitive advantage in the clean energy and digital economy.

References

1. Ministry of Environment, Forest and Climate Change, Press Information Bureau (PIB). (2022, December 22). India stands committed to reduce Emissions Intensity of its... - PIB. Press Information Bureau. https://www.pib.gov.in/PressReleasePage.aspx?PRID=1885731
2. RMI, & NITI Aayog. (2022). Harnessing Green Hydrogen: Opportunities for Deep Decarbonization in India. RMI. https://rmi.org/insight/harnessing-green-hydrogen/
3. Sebastian, S., Wijewardane, S., & Srinivasan, S. (2023). Recent advances in hydrogen production, storage, and fuel cell technologies with an emphasis on inventions, innovations, and commercialization. Solar Compass, 8, Article 100065. https://doi.org/10.1016/j.solcom.2023.100065
4. Aminaho, E. N., Aminaho, N. S., & Aminaho, F. (2025). Techno-economic assessments of electrolyzers for hydrogen production. Applied Energy, 399, Article 126515. https://doi.org/10.1016/j.apenergy.2025.126515
5. International Energy Agency (IEA). (2025). Global Hydrogen Review 2025. IEA. https://www.iea.org/reports/global-hydrogen-review-2025/executive-summary
6. Basirat, S., & Nicholas, S. (2023). Green steel for Europe, blast furnaces for India. IEEFA. https://ieefa.org/sites/default/files/2023-02/ArcelorMittal-Green-Steel-for-Europe-blast-furnaces-for-India_Feb2023_0.pdf
7. Bain & Company, CII, and RMI. (2025). From Promise to Purchase: Unlocking India's Green Hydrogen Demand. Retrieved from https://rmi.org/insight/from-promise-to-purchase
8. Corporate Europe Observatory. (2023, October 3). The dirty truth about the EU's hydrogen push. Corporate Europe Observatory. Retrieved from https://corporateeurope.org/en/dirty-truth-about-EU-hydrogen-push
9. International Energy Agency (IEA). (2025). Global Hydrogen Review 2025. IEA. Retrieved from https://www.iea.org/reports/global-hydrogen-review-2025/executive-summary
10. Ministry of New & Renewable Energy, Government of India. (n.d.). Demand Creation. National Green Hydrogen Mission.
11. Biswas, T., Yadav, D., & Baskar, A. G. (2020, December 13). A Green Hydrogen Economy for India: Policy and Technology Imperatives to Lower Production Cost. Council on Energy, Environment and Water (CEEW).



12. Gupta, U. (2025). NTPC REL wins SECI auction for 70,000 MT/year green ammonia supply. https://www.pv-magazine-india.com/2025/08/05/ntpc-rel-wins-seci-auction-for-70000-mt-year-green-ammonia-supply/
13. Pathak, K. (2025). RIL targets green hydrogen output at a cost of $1/kg. RIL targets green hydrogen output at a cost of $1/kg
14. Pathak, C. (2025) Insights from SIGHT Scheme: SECI Green Ammonia tender.
15. PIB. (2025). SECI conducts first-ever auction for procurement of Green Ammonia under National Green Hydrogen Mission. Retrieved from Press Release:Press Information Bureau
16. International Energy Agency (IEA). (2024). Global Hydrogen Review 2024. IEA.
17. JMK Research & Analytics. (2020). What led to historic low solar tariff of Rs 2/ kWh in India? JMK Research & Analytics.
18. U.S. Department of Energy. (2024, May 20). Clean Hydrogen Production Cost Scenarios with PEM Electrolyzer Technology (DOE Hydrogen Program Record No. 24005). U.S. Department of Energy. Retrieved from https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/24005-clean-hydrogen-production-cost-pem-electrolyzer.pdf
19. Mishra, A., & Mampilly, D. J. (2024, January 3). Year End Review 2023 of Ministry of New & Renewable Energy. Press Information Bureau, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=1992732
20. Gupta, U. (2025, May 27). SECI awards 420 MW renewables-plus-storage at average price of $0.059 /kWh. pv magazine India. Retrieved from https://www.pv-magazine-india.com/2025/05/27/seci-awards-420-mw-renewables-plus-storage-at-average-price-of-0-059-kwh/
21. Petroleum and Natural Gas Regulatory Board (PNGRB). (2025, March 6). Press Note: Hydrogen. Retrieved from https://www.pngrb.gov.in/pdf/press-note/20250306_Hydrogen.pdf
22. IANS. (2024, April 1). Industry body IH2A proposes 10% hydrogen purchase obligation for existing refinery, ammonia plants. The Economic Times. Retrieved from https://energy.economictimes.indiatimes.com/news/renewable/industry-body-ih2a-proposes-10-hydrogen-purchase-obligation-for-existing-refinery-ammonia-plants/121000163
23. Bain & Company, Confederation of Indian Industry (CII), & Rocky Mountain Institute (RMI). (2025, June 19). From Promise to Purchase: Unlocking India's Green Hydrogen Demand. Retrieved from https://rmi.org/insight/from-promise-to-purchase/
24. Ministry of New & Renewable Energy. (2025, August 25). India is on track to exceed its NDC targets by 2030, says Union Power & NRE Minister Shri R.K. Singh. Press Information Bureau, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=1950421
25. European Commission. (n.d.). Carbon Border Adjustment Mechanism. Taxation and Customs Union. Retrieved September 15, 2025, from https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en
26. Ministry of New and Renewable Energy. (2024, May). Green Hydrogen Standards and Approval Systems in India. Press Information Bureau. Retrieved from https://static.pib.gov.in/WriteReadData/specificdocs/documents/2024/may/doc2024510336201.pdf
27. Ministry of New & Renewable Energy. (2022, December 29). Shri RK Singh launches an online portal for the registration of Carbon Credit Trading Scheme. Press Information Bureau, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=1888547

28. Lerh, J. (2024, October 30). Zero-carbon ammonia for shipping faces cost, safety challenges. Reuters. https://www.reuters.com/markets/commodities/zero-carbon-ammonia-shipping-faces-cost-safety-challenges-2024-10-27/

29. European Commission. (n.d.). Carbon Border Adjustment Mechanism. Taxation and Customs Union. Retrieved September 15, 2025, from https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en

30. Ministry of New & Renewable Energy. (2025, May 22). SECI signs MoU with the Department of Investment Promotion, Government of Thailand. Press Information Bureau, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2107795

31. IEA Bioenergy. (2025). Annual Report 2024. IEA Bioenergy Technology Collaboration Programme. Retrieved from https://www.ieabioenergy.com/wp-content/uploads/2025/06/IEA-Bioenergy-Annual-Report-2024.pdf

32. Central Pollution Control Board. (n.d.). Central Pollution Control Board. Government of India. Retrieved from https://cpcb.nic.in/

33. Santos, S. M., Assis, A. C., Gomes, L., Nobre, C., & Brito, P. (2023). Waste Gasification Technologies: A Brief Overview. Waste, 1(1), 140-165. https://doi.org/10.3390/waste1010011

34. The Editors of Encyclopaedia Britannica. (n.d.). Pyrolysis. In Britannica. Retrieved from https://www.britannica.com/science/pyrolysis

35. Plastics Industry Association. (2025). How Pyrolysis Oil is Made and Why It Matters. Plastics Industry Association. Retrieved from https://www.plasticsindustry.org/articles/how-pyrolysis-oil-made-why-it-matters/

36. Green Hydrogen Organisation. (n.d.). India. Green Hydrogen Organisation. Retrieved from https://gh2.org/countries/india

37. Hosansky, D. (2023, March 20). Plasma arc gasification. Britannica. Retrieved September 15, 2025, from https://www.britannica.com/technology/plasma-arc-gasification

38. Mauchline, David & Merwe, Andre & van der Walt, Izak. (2024). Review of the current state-of-the-art in plasma gasification of municipal and medical waste. MATEC Web of Conferences. 406. 05008. 10.1051/matecconf/202440605008.

39. United Nations Environment Programme. (2024). Global waste management outlook 2024: Beyond an age of waste—Turning rubbish into a resource. UNEP; International Solid Waste Association. https://www.unep.org/resources/global-waste-management-outlook-2024

40. Banerjee, B. (2023, August 24). How India can rejuvenate its Waste-to-Energy sector. CSTEP. https://cstep.in/publications-details.php?id=2590

41. Blackridge Research & Consulting. (2024, January 24). India Waste-to-Energy (WTE) Market Outlook to 2030. Blackridge Research & Consulting. Retrieved from https://www.blackridgeresearch.com/reports/india-waste-to-energy-wte-market

42. Ministry of New and Renewable Energy. (2025, September 11). Waste to Energy Overview. https://mnre.gov.in/en/waste-to-energy-overview/
43. Mundhra, J. (2025, June 29). #18: Why Over 50% of India's Waste-to-Energy Plants Have Already Shut Down?. Bharatnama. https://bharatnama.substack.com/p/18-why-over-50-of-indias-waste-to
44. Blackridge Research & Consulting. (2024, January 24). India Waste-to-Energy (WTE) Market Outlook to 2030. Blackridge Research & Consulting. Retrieved from https://www.blackridgeresearch.com/reports/india-waste-to-energy-wte-market
45. Press Information Bureau (PIB). (2022, December 20). Ministry of New and Renewable Energy initiates National Bio Energy Programme to utilize surplus biomass for power generation. Retrieved from https://www.pib.gov.in/PressReleasePage.aspx?PRID=1885073
46. Centre for Financial Accountability. (2022). India's waste to energy paradigm: A policy, environmental and social perspective. Centre for Financial Accountability. https://www.cenfa.org/wp-content/uploads/2022/12/INDIAS-WASTE-TO-ENERGY-PARADIGM.pdf
47. Saha, A., Sarkar, A., & Bhoumik, A. (2017). Energy recovery from waste in India: An evidence-based analysis. Sustainable Energy Technologies and Assessments, 21, 23-32. https://doi.org/10.1016/j.seta.2017.04.003
48. Ahluwalia, I. J., & Patel, U. (2018). Solid waste management in India: An assessment of resource recovery and environmental impact (Working Paper No. 356). Indian Council for Research on International Economic Relations (ICRIER). https://hdl.handle.net/10419/203690
49. Karmakar, A., Daftari, T., Sivagami, K., Chandan, M. R., Shaik, A. H., Kiran, B., & Chakraborty, S. (2023). A comprehensive insight into Waste to Energy conversion strategies in India and its associated air pollution hazard. Environmental Technology & Innovation, 29, 103017. https://doi.org/10.1016/j.eti.2023.103017
50. Kaur, G., Singh, M., & Singh, R. (2024). The role of government policies and incentives in promoting waste-to-energy projects in India: A case study approach. International Journal of Environmental Technology and Management, 33(1), 29-45. https://doi.org/10.1504/ijetm.2024.10066224
51. Pandey, A., Chauhan, A., Pandey, D., & Singh, S. (2024). A comprehensive review of waste-to-energy technologies: Pathways for large-scale applications. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-024-33230-6
52. Wright, A. (2024, September 22). The Growth of India's Semiconductor Industry to $110 Billion By 2030. Wright Research. Retrieved from https://www.wrightresearch.in/blog/the-growth-of-indias-semiconductor-industry-to-110-billion-dollar-by-2030/
53. MarkNtel Advisors. (2024). India Semiconductor Market Size, Value & Growth Analysis, 2030. Retrieved from https://www.marknteladvisors.com/research-library/india-semiconductor-market.html
54. PIB. (2025). Government of India taking steps to encourage domestic manufacturing of semiconductors & promote country's digital transformation and self-reliance. Retrieved from Press Release:Press Information Bureau
55. DenDanto. (2025). Semiconductor expansion may require smart capital spending processes. Retrieved from Semiconductor expansion may require smart capital spending processes | Deloitte US

56. Micron. (2023). Micron Announces New Semiconductor Assembly and Test Facility in India. Retrieved from Micron Announces New Semiconductor Assembly and Test Facility in India | Micron Technology

57. Wiseman, B., Marcil, H., de Jong, M., Wagner, R., Roundtree, T., & Stopford, T. (2025, April 21). Semiconductors have a big opportunity—but barriers to scale remain. McKinsey & Company. Retrieved September 15, 2025, from https://www.mckinsey.com/industries/semiconductors/our-insights/semiconductors-have-a-big-opportunity-but-barriers-to-scale-remain

58. Chaudhuri, R., & Bhandari, K. (2025). India's Semiconductor Mission: The Story So Far. Carnegie Endowment for International Peace. Retrieved from https://carnegieendowment.org/research/2025/08/indias-semiconductor-mission-the-story-so-far?lang=en

59. Press Information Bureau (PIB). (2025, August 12). Cabinet approves semiconductor manufacturing units in ODISHA, PUNJAB and ANDHRA PRADESH with an outlay of Rs.4600 crore. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2155456

60. India Cellular & Electronics Association (ICEA). (2024). The challenges and opportunities in Indian Semiconductor Industry. Retrieved from https://icea.org.in/wp-content/uploads/2024/11/0.1-The-challenges-and-opportunities-in-Indian-Semiconductor-Industry.pdf

61. Cyrill, M., & Kapur, Y. (2025, June 3). Setting up a Semiconductor Fabrication Plant in India: What Foreign Investors Should Know. India Briefing. https://www.india-briefing.com/news/setting-up-a-semiconductor-fabrication-plant-in-india-what-foreign-investors-should-know-22009.html

62. NITI Aayog. (2022). Export Preparedness Index 2022. Government of India. https://www.niti.gov.in/sites/default/files/2023-07/Export-Preparedness-Index-2022_0.pdf

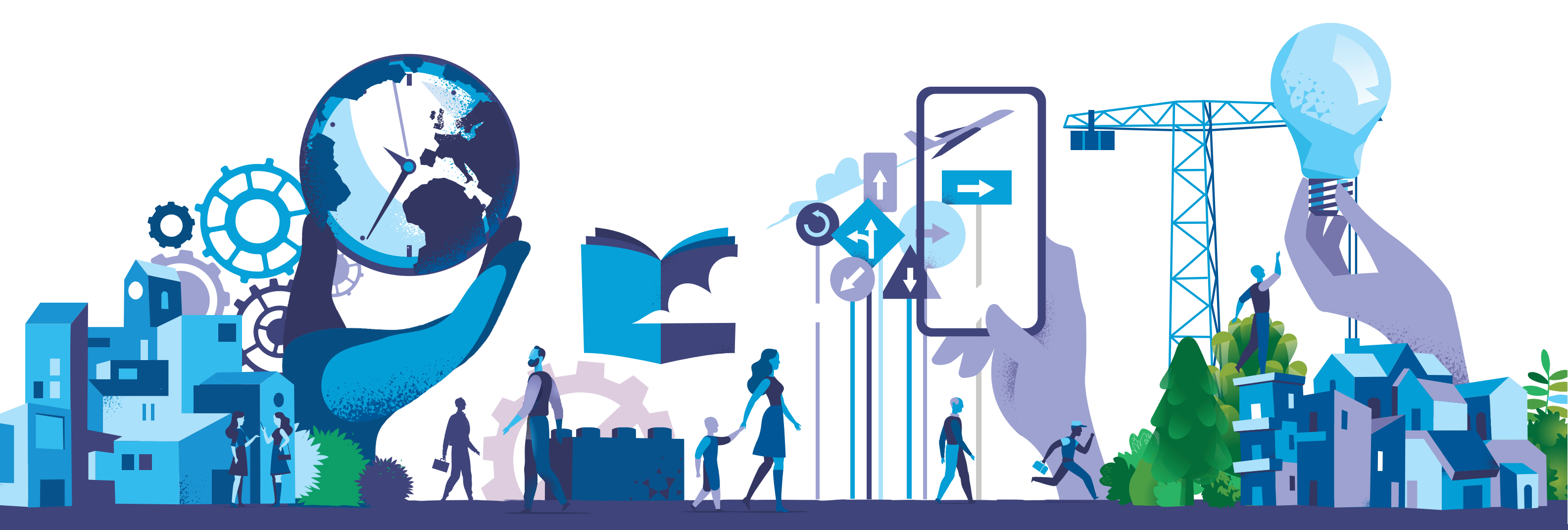
63. Varas, A., Varadarajan, R., Palma, R., Goodrich, J., & Yinug, F. (2021, April 1). Strengthening the global semiconductor supply chain in an uncertain era. Boston Consulting Group; Semiconductor Industry Association. Retrieved September 15, 2025, from https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/

64. Jefferies. (2025, March). India's semiconductor industry faces supply chain and limited talent challenges: Jefferies report, Retrieved from India's semiconductor industry faces supply chain and limited talent challenges: Jefferies report - The Economic Times

65. ICEA. (2024). The Challenges and Opportunities in the Indian Semiconductor Industry, Retrieved from 0.1-The-challenges-and-opportunities-in-Indian-Semiconductor-Industry.pdf

66. PIB. (2022). MeitY invites applications under the Chips to Startup (C2S) Programme from academia, R&D organisations, startups and MSMEs, Retrieved from MeitY invites applications under the Chips to Startup (C2S) Programme from academia, R&D organisations, startups and MSMEs

67. Burkacky, de Jong, Mittal, Verma. (2021). Value creation: How can the semiconductor industry keep outperforming?, from Value creation: How can the semiconductor industry keep outperforming? | McKinsey



68. Organisation for Economic Co-operation and Development. (2025). Mapping the semiconductor value chain: Working towards identifying dependencies and vulnerabilities. OECD Publishing. https://doi.org/10.1787/4154cdbf-en
69. The McClean Report: A Complete Analysis and Forecast of the Semiconductor Industry. Retrieved from https://www.techinsights.com/products-services/semiconductor-market-analysis/mcclean-report
70. Chaudhuri, R., & Bhandari, K. (2025). India's Semiconductor Mission: The Story So Far. Carnegie Endowment for International Peace. Retrieved from https://carnegieendowment.org/research/2025/08/indias-semiconductor-mission-the-story-so-far?lang=en
71. McKinsey & Company. (2022). Chipmaking for the future: Semiconductors are back—and so is an industry race. Retrieved from https://www.mckinsey.com/industries/semiconductors/our-insights/chipmaking-for-the-future-semiconductors-are-back-and-so-is-an-industry-race
72. Cyrill, M., & Kapur, Y. (2025, June 3). Setting up a Semiconductor Fabrication Plant in India: What Foreign Investors Should Know. India Briefing. https://www.india-briefing.com/news/setting-up-a-semiconductor-fabrication-plant-in-india-what-foreign-investors-should-know-22009.html
73. India Cellular & Electronics Association (ICEA). (2024, April 25). The challenges and opportunities in Indian Semiconductor Industry. Retrieved from https://icea.org.in/wp-content/uploads/2024/11/0.1-The-challenges-and-opportunities-in-Indian-Semiconductor-Industry.pdf
74. Bhandari, K. (2025, September 1). India's Semiconductor Mission: The Story So Far. Carnegie Endowment for International Peace. https://carnegieendowment.org/research/2025/08/indias-semiconductor-mission-the-story-so-far?lang=en
75. Vibhuti, G. (2025, June 6). India's power-hungry data centre sector at a crossroads. IEEFA. https://ieefa.org/resources/indias-power-hungry-data-centre-sector-crossroads
76. Arizton Advisory & Intelligence. (2024). India Artificial Intelligence Market Size & Outlook, 2030. Retrieved from https://www.arizton.com/market-reports/india-artificial-intelligence-market-size-and-outlook-2030
77. IBM Newsroom. Retrieved from https://newsroom.ibm.com/2024-02-26-New-IBM-Study-Data-Reveals-74-of-Energy-Utility-Companies-Surveyed-Embracing-AI
78. Garg, V. (2025, June 6). India's power-hungry data centre sector at a crossroads. Institute for Energy Economics and Financial Analysis (IEEFA). Retrieved September 15, 2025, from https://ieefa.org/resources/indias-power-hungry-data-centre-sector-crossroads
79. Karlekar, J. (2025, April). India Data Centre Market Dynamics. JLL. https://www.jll.com/en-in/insights/market-dynamics/india-data-centers
80. Nemiraj, V. (2025, March 13). Powering India's Data Center Boom. Entrepreneur. https://www.entrepreneur.com/en-in/news-and-trends/powering-indias-data-center-boom/488459
81. Sokolowski, S. (2022, May 2). Data Center Investment in India Is Poised for Massive Growth. Data Center Frontier. https://datacenterfrontier.com/data-center-investment-in-india-is-poised-for-massive-growth/
82. Wang, S., Li, H., & Chen, J. (2025). Navigating the Data Center Boom: A Strategic Framework for Sustainable Growth in India. Journal of Sustainable Technology and Policy. https://doi.org/10.1108/JSTP-2025-0012

83. Sandalow, D., Fan, Z., Carter, M. (2024). Can AI Transform the Power Sector?. Retrieved from Can AI Transform the Power Sector? - Center on Global Energy Policy at Columbia University SIPA | CGEP %

84. Henao, F., Edgell, R., Sharma, A. et al. AI in power systems: a systematic review of key matters of concern. Energy Inform 8, 76 (2025). https://doi.org/10.1186/s42162-025-00529

85. The LinkedIn Global Talent Trends Report 2024. Retrieved from https://www.linkedin.com/business/talent/blog/talent-trends/global-talent-trends-2024

86. International Energy Agency. (2025). Data centre energy use: Critical review of models and results. IEA Technology Collaboration Programme, 4E. https://www.iea-4e.org/wp-content/uploads/2025/05/Data-Centre-Energy-Use-Critical-Review-of-Models-and-Results.pdf

87. Cai, W., Qin, L., & Huang, J. (2024). MoC-System: Efficient Fault Tolerance for Sparse Mixture-of-Experts Model Training. arXiv, arXiv:2408.04307. https://doi.org/10.48550/arXiv.2408.04307

88. ILO, & Institute for Human Development. (2024). India Employment Report 2024: Youth employment, education and skills. International Labour Office. https://www.ilo.org/sites/default/files/2024-08/India%20Employment%20-%20web_8%20April.pdf

89. PIB. (2023). India needs to create approximately 7.85 million jobs each year in the non-farm sector until 2030 to accommodate its growing workforce. Retrieved from Press Release: Press Information Bureau

90. Ministry of Finance, Government of India. (2025). Economic Survey 2024-25. India Budget. https://www.indiabudget.gov.in/economicsurvey/

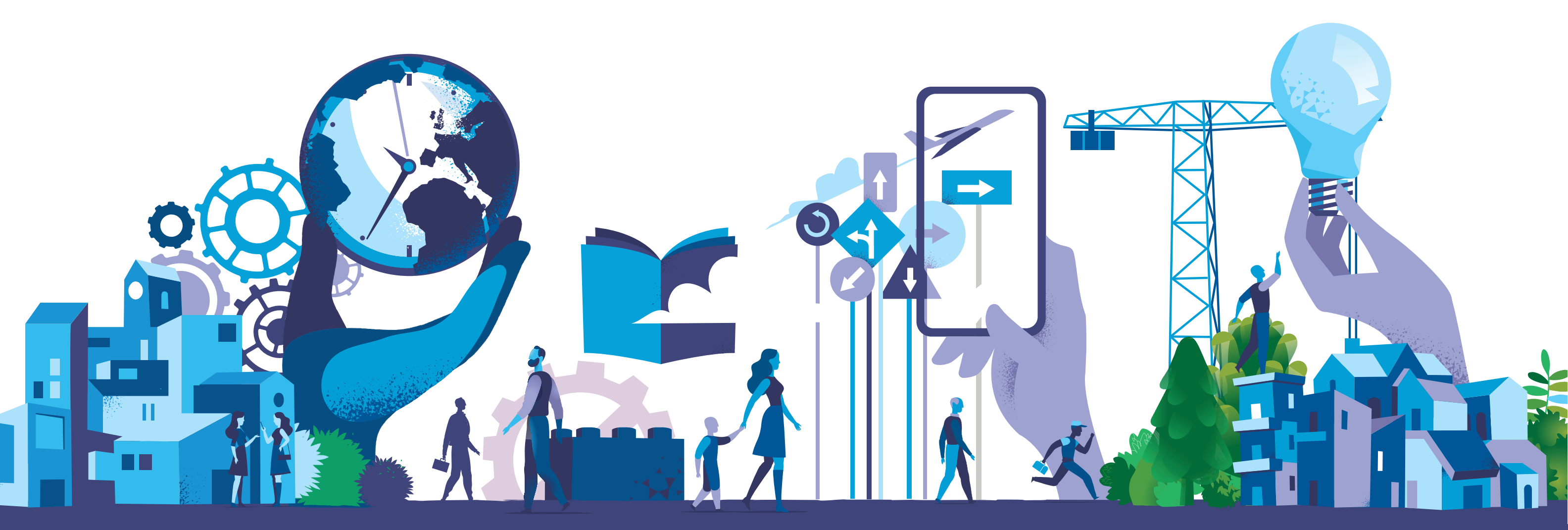
91. NLB Services. (2024). India's Green Job Market Report: A 2024 Analysis. Retrieved from https://www.nlbservices.com/report-analysis

92. Yanez Pagans, M., Ham, A., & Vazquez, E. J. (2025). Equipping India's workforce for the green transition. World Bank Blogs. https://blogs.worldbank.org/en/endpovertyinsouthasia/equipping-india-s-workforce-to-support-its-green-transition

93. ET Edge Insights. (2025). Bridging the semiconductor skills gap: Building a future-ready workforce. Retrieved from https://etinsights.et-edge.com/

94. Azeem, S. (2024, June 11). India's semiconductor sector to face crunch of 3 lakh professionals by 2027. Fortune India. https://www.fortuneindia.com/macro/indias-semiconductor-sector-to-face-crunch-of-3-lakh-professionals-by-2027/117131

95. Ezell, S. (2024, February 14). India's Semiconductor Readiness: How India Can Better Compete in the Global Chip Race. Information Technology and Innovation Foundation. https://itif.org/publications/2024/02/14/india-semiconductor-readiness/



96. ET Edge Insights. (2025). Bridging the semiconductor skills gap: Building a future-ready workforce. Retrieved from https://etinsights.et-edge.com/

97. Zetwerk. (2024, October 15). Closing the Skills Gap in India's Growing Semiconductor and Electronics Sectors. Retrieved from https://www.zetwerk.com/press-media/closing-the-skills-gap-in-indias-growing-semiconductor-and-electronics-sectors/

98. Al-Hajj, M., & O'Sullivan, J. (2025, September 22). Power utilities need digital talent, but not all are searching for it. International Energy Agency. https://www.iea.org/commentaries/power-utilities-need-digital-talent-but-not-all-are-searching-for-it

99. NLB Services. (2024). India's Green Job Market Report: A 2024 Analysis. Retrieved from https://www.nlbservices.com/report-analysis

100. International Business Machines Corporation. (2024, February 26). New IBM Study Data Reveals 74% of Energy & Utility Companies Surveyed Embracing AI. IBM Newsroom. Retrieved September 15, 2025, from https://newsroom.ibm.com/2024-02-26-New-IBM-Study-Data-Reveals-74-of-Energy-Utility-Companies-Surveyed-Embracing-AI

101. Nghiem, A., Casanovas, M., Laera, S., & Lachmann, S. (2024, June 11). Power utilities need digital talent – but not all are searching for it. International Energy Agency. https://www.iea.org/commentaries/power-utilities-need-digital-talent-but-not-all-are-searching-for-it

102. Sarkar, B. (2024, October 17). India Inc intensifies training efforts to bridge semiconductor skills gap. The Economic Times. Retrieved from https://m.economictimes.com/topic/GPU-acquisition

103. Social Policy Research Foundation. (2025, May 20). Unpacking the current scenario of India's skilling landscape. Social Policy Research Foundation. https://sprf.in/unpacking-the-current-scenario-of-indias-skilling-landscape/

104. The Economic Times. (2024, October 17). India Inc intensifies training efforts to bridge semiconductor skills gap. Retrieved from https://economictimes.indiatimes.com/

105. Tripathy, P. (2025, January 20). Empowering India's Future Workforce with Green Skills and Technology. National Skills Network.

106. Sarkar, B. (2024, June 20). To address talent shortage, chipmakers skilling engineering students. The Economic Times. https://economictimes.indiatimes.com/jobs/fresher/to-address-talent-shortage-chipmakers-skilling-engineering-students/articleshow/111118362.cms

107. ET Bureau. (2024, September 12). Lam Research adds 20 India universities to initiative to upskill future semiconductor talent via Semiverse™ Solutions Virtual Infrastructure. The Economic Times. https://economictimes.indiatimes.com/

108. Majumdar, D. (2024, December 11). Micro-credentialing on the rise in India: Coursera data. The Economic Times. https://economictimes.indiatimes.com/jobs/fresher/micro-credentialing-on-the-rise-in-india-coursera-data/articleshow/111118362.cms

109. Fuel Cells and Hydrogen Joint Undertaking. (2021, June 2). Hydrogen Valleys: Insights into the emerging hydrogen economies around the world. European Union Retrived from.https://h2v.eu/media/7/download

110. Korea European Research Center. (2022, July 15). K-ERC: Korea R&D research trends and results. K-ERC. https://k-erc.eu/2022/07/korea-rd-research-trends-and-results/9817/

111. Ministry of Skill Development and Entrepreneurship. (2021). Annual Report 2020-21. Government of India. https://www.msde.gov.in/static/uploads/2024/02/20-21AR.pdf

112. Japan. Ministry of the Environment. (2025). Regional Decarbonization Seminar. Decarbonized Regional Development Support Site. Retrieved from https://ondanka-shien.env.go.jp/decarbonization/seminar/

113. India. Ministry of Environment, Forest and Climate Change. (2017). National Mission for a Green India (GIM) Mission Document-1. Government of India. https://moef.gov.in/uploads/2017/08/GIM_Mission-Document-1.pdf

114. Leong, L. (2024, May 14). Singapore, US expand AI partnership to focus on upskilling youth and women. ZDNET. https://www.zdnet.com/article/singapore-us-expand-ai-partnership-to-focus-on-upskilling-youth-and-women/