Bharat Cleantech Manufacturing Platform: R&D and Product Innovation

Accelerating an Aatmanirbhar, Green and Viksit Bharat

bharat CLIMATE FORUM

Council for International Economic Understanding

Dalberg

As India rapidly moves towards meeting its NDCs, indigenisation of cleantech manufacturing is critical for an *Aatmanirbhar* and *Viksit Bharat*

India has national targets and projections across renewable energy and e-mobility for 2030…

300 GW Solar *installed capacity*[1]

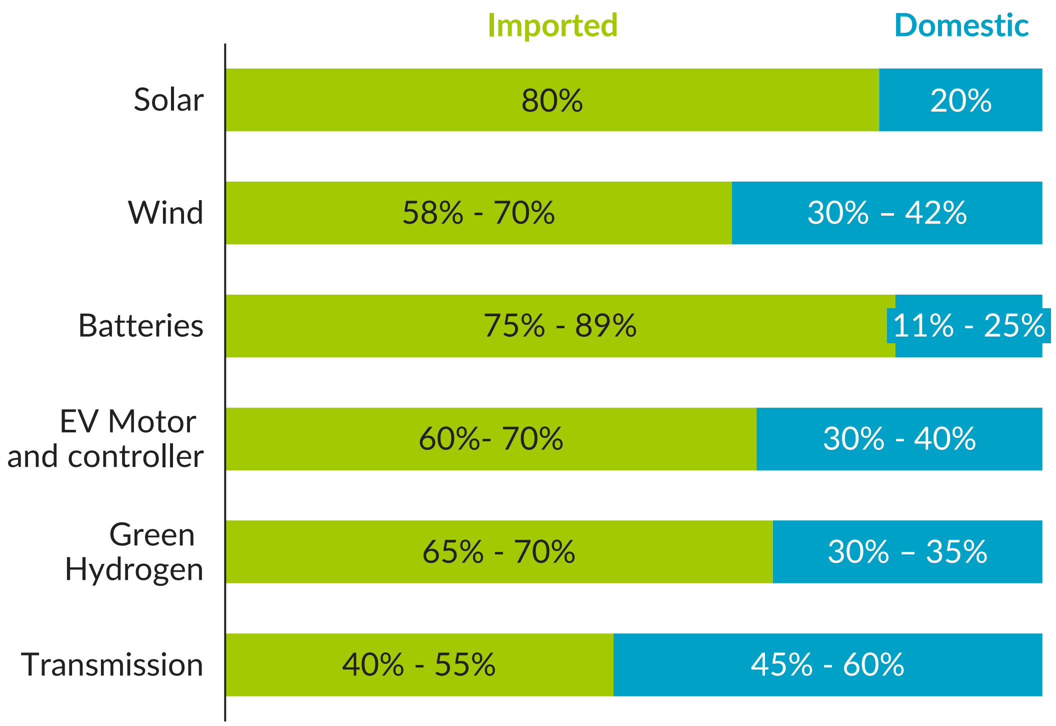
30% EV *sales penetration*[2]

100 GW Wind *installed capacity*[3]

5 MTPA Green Hydrogen *production*[4]

… but cleantech supply chains are heavily import-dependent and need to be indigenised for an Aatmanirbhar Bharat

Cleantech manufacturing import dependence across the value chain, 2023



Source: (1) MNRE; Solar capacity projection extrapolated from CEA's 2032 Solar capacity projections, assuming linear growth in capacity; (2) NITI Aayog ; (3) ET ; (4) MNRE - NGHM; MNRE, Ministry of Power; Economics Times; BNEF's installed and announced capacity; IEA, India – World Energy Investment 2024 – Analysis; NITI, India's Power Sector | Capacity & Generation Mix; PIB, India's Ethanol Push: A Path to Energy Security, CEEW, Strengthen India's Clean supply chain, 2024; Bain, India Electric Vehicle Report, 2023; Policy circle; Economist Impact, Scaling clean energy: financing and transition strategies for India's sustainable future

The Platform could support the National Manufacturing Mission to target at least 50% indigenisation of cleantech manufacturing value chains by 2030 enabling net-zero ambition with indigenous production

The Platform's potential to accelerate development of incremental indigenous capacity can be observed across sectors

Sector-wise goals

	Solar	Wind	BESS	E-mobility	Green Hydrogen	Transmission
Installed capacity						
2030 targets	300 GW[1]	100 GW[2]	230-240 GWh[3]	30@30[4]	5 MTPA[6]	648,190[7] ckm
% value chain indigenisation*						
Current levels (est.)	~20%	~35%	~20%	~35%[5]	~35%	~55%
2030 target (Proposed)	~50%	~60%	~45%	~50%	~60%	~70%

May decline due to shifting and unstable demand of domestic components amid intensified global competition

Note: *Indigenisation is domestic value contribution across cleantech value chain from raw materials to end production for all components; : (1) MNRE; (2) ET; (3) Estimated requirements under National Electricity Plan (NEP) 2023 of CEA; (4) NITI Aayog ; (5) For EV Motors and controllers; (6) MNRE - NGHM (7) 2032 target from National Electricity Plan Volume II – Transmission of CEA

Source: MNRE, Ministry of Power; Economics Times; BNEF's installed and announced capacity; IEA, India – World Energy Investment 2024 – Analysis; NITI, India's Power Sector | Capacity & Generation Mix; PIB, India's Ethanol Push: A Path to Energy Security, NEP 2023 of CEA; EV Reporter, India's electric vehicle supply chain landscape | An overview, 2024

A detailed strategy and action plan for the focus sectors would be developed to achieve these goals and objectives and build the cleantech indigenisation pathways for these sectors

Sector-wise gaps would be identified and addressed with all stakeholders across each cross-cutting theme in alignment with the National Manufacturing Mission

Enablers:
Policy recommendations; Trade partnerships; Public and private stakeholder recommendations; Demand and supply drivers; Leveraging AI for Climate and cleantech manufacturing

Sectors: Solar | Wind | BESS | E-mobility | Green Hydrogen | Transmission

Cross-cutting themes

Demand & Market Architecture	*Drive demand and adoption of output, incl. **Quality Control Orders (QCOs)***	
R&D & Product Innovation	*Drive technology sharing, adoption and indigenous R&D*	*Detailed ahead*
Upstream Raw Materials & Critical Inputs	*Streamline raw material sourcing (e.g. critical rare earth elements; bio-energy feedstock etc.)*	
Capital Equipment & Infrastructure	*Address machinery sourcing & infrastructure requirements (e.g., grid connectivity)*	
Talent & Workforce	*Bridge skilling gaps for specialised and non-specialised workforce*	
Financing & Taxation	*Identify financial instruments and mechanisms to reduce the funding gap* *Identify levers to improve **Ease of Doing Business** to attract investments*	

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TABLE OF CONTENTS

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SECTION ONE

CLEANTECH MANUFACTURING AND R&D ECOSYSTEM

R&D would be a critical enabler to meet these goals and help India shift focus from technology import to indigenous innovation

Until recent years, focus was on deployment by scaling up existing global technologies in India

Stronger historical focus on deployment and assembly vs. upstream value chain integration

- Bulk of government **policies focused on deployment** such as RPOs, Open Access policies, PM KUSUM scheme
- Siloed focus on deployment led to **heavy import dependence** on China (80% for solar cells, over 90% for batteries etc.)
- Non-tariff barriers, PLI schemes have started focusing on manufacturing only in recent years, but **upstream integration is slow** (e.g. 75 GW module manufacturing capacity vs. 25 GW solar cells)

Accelerated scale-up of global technologies without adapting for Indian climate and conditions led to adoption hindrances

- Global tech **not adapted to India** for EV battery packs led to fire incidents due to **low tolerance for Indian heat** and climate conditions and potentially **impacted EV adoption** in early years
- Resolving this through R&D and innovation addressed the issues but still **restricted focus on assembly vs. innovation**

Recent trends show green shoots in domestic R&D fueled by public and private sector initiatives

Greater institutional and budgetary focus from government

- **Anusandhan National Research Foundation (ANRF), 2023** established to support basic research and prototyping across universities, R&D labs, etc. **Priority areas include cleantech**[1]
- Corpus of **INR 1 lakh crore** to **accelerate private sector R&D** introduced in 2024-25 Union Budget to **boost "sunrise tech" including cleantech**[1]

Increased R&D investments by private sector and startups

- **Increased R&D centers** setup by automotive OEMs. E.g., 149 EV-related patents granted to Mahindra Research Valley[2]
- **Private sector-academia collaborations** have also started focusing on cleantech. E.g., Zinc-air battery prototype development at IIT Madras supported by Hindustan Zinc[3]

Source: (1) PIB, Union Budget 2024-25; (2) Mahindra Rise; (3) Hindustan Zinc

Focused government initiatives have catalyzed private sector investments and scaled R&D and innovations globally – similar efforts could leapfrog cleantech manufacturing in India

ILLUSTRATIVE | NON-EXHAUSTIVE

EU, China, South Korea and US lead global cleantech innovations with focused public and private sector efforts

Country/ Region	Key interventions	Details	Technology Impact
EU	**Green New Deal, 2019**	• Policies to achieve net zero emissions by 2050 • EUR 100 Bn to support cleantech manufacturing • Revised EU ETS targets (≥55% emissions cut by 2030 vs. 1990 baseline)	• Net-Zero Industry Act launched to scale cleantech manufacturing capacity and meet ≥40% of annual deployment capacity by 2030 • Funding provided for demonstration of innovative low-carbon tech and awarded to 210+ projects in renewables, hydrogen, CCUS, storage and net-zero mobility
	Project Horizon, 2021-27	• EUR 96 Bn for R&D to market in Climate, Energy, Mobility (among others)	• EUR 12 Bn in startup funding, which secured EUR 70 Bn VC funds
China	**Made in China (MIC), 2025**	• 10-year plan (2015–25) to scale high-tech manufacturing in 10 sectors • USD 200 Bn for R&D and manufacturing for semiconductors	• Fastest prototyping to commercialization across cleantech sectors • Promoted breakthrough development in sectors such as CNC/robots, NEVs, power equipment, new materials • Supported green manufacturing via R&D of advanced Greentech
Korea	**2050 Carbon Neutral Energy Technology Roadmap, 2021**	• National technology acquisition strategy for carbon neutrality by 2050 • Government to invest ~USD 60 Mn in 2025	• 197 focus technologies identified in 13 energy areas (e.g. PV solar, fuel cell, green hydrogen, energy storage, etc.)
US	**IRA and CHIPS and Science Act, 2022**	• USD 53 Bn- R&D and semiconductor manufacturing incentives (CHIPS) • Manufacturing grants and R&D infrastructure access via DARPA	• USD 224 Bn in cleantech and semiconductor manufacturing projects announced since IRA and CHIPS Act • At least 305 major clean-energy projects have been announced in the US

Source: EU, Delivering the European Green Deal; EU-Startups- Represents collective funding figure by European Union Framework Programmes including Horizon Project; OECD, Science, Technology and Innovation Outlook 2023; Institute for Security & Development Policy, MIC Background; Mission Innovation, National Innovation Pathway Round-Up; KEEi- represents overall fund commitment, might include other tech-related plans too; FDI Intelligence; CINEA, Five years of the Innovation Fund: accelerating the clean industrial transition

SECTION TWO

OPPORTUNITIES AND CHALLENGES TO SCALING-UP CLEANTECH R&D IN INDIA

There are several opportunities that could be captured through increased R&D investment to accelerate cleantech manufacturing indigenisation

45+
potential cleantech innovations tech transferred or commercialized by 2030[1]

INR 4,900-7,700 Cr
government funding for R&D investments required across sectors

50-65
development and testing labs can be set up or upgraded

Accelerated commercialization
of high-potential cleantech innovations

Global leadership
potential in cleantech supply chains

(1) With the goal of 10-20 cleantech innovations per focus sector of Bharat Cleantech Manufacturing Platform; Source: Dalberg analysis, expert consultations

Despite recent momentum, India faces challenges of tech identification, R&D infrastructure, financing and governance which need to be overcome to scale R&D for cleantech (1/2)

India's R&D and innovation success in other industries such as pharmaceuticals, defense and space-tech could provide inspiration for overcoming these challenges and scaling cleantech R&D

Key challenges	Public sector/academia	Private sector
Identification & discoverability (for cleantech innovation)	• **Weak incentives** for HEIs researchers to move research toward prototyping • **Limited collaborative effort for tech identification:** ○ **Fragmented global and domestic partnerships** for identifying India-relevant technologies ○ **Underperforming tech transfer offices (TTOs)** – ~60% cite lack of practical capacity	**Limited tech identification and collaboration:** • **Recent, yet limited, focus on identifying prototypes** for indigenous scale-up • **Fragmented partnerships** with academia and start-ups; incumbents often work in silos
R&D infrastructure	• **Outdated facilities** and limited access to testing equipment • **Few open-access cleantech labs** beyond select Atal Incubation Centers and IITs • **Underutilized** government-owned **Centers of Excellence**	**Nascent, but limited cleantech R&D infra investments and collaboration:** • **Early-stage investments by select players** (e.g. Mahindra, Adani, Waaree) • **Limited academia tie-ups** (e.g. Waaree–IIT Bombay, Hyundai–IIT Madras)

Source: Expert inputs; CTIER; Atal Innovation Mission-Selected Atal Incubation Centre; DST-CPR, Study of Technology Transfer Centres to Increase Commercialization of Innovations; NITI Aayog, A New Lens for Innovation of New India; PIB report, Ministry of Defence 2025; Invest India; Company websites and annual reports

Despite recent momentum, India faces challenges of tech identification, R&D infrastructure, financing and governance which need to be overcome to scale R&D for cleantech (2/2)

India's R&D and innovation success in other industries such as pharmaceuticals, defense and space-tech could provide inspiration for overcoming these challenges and scaling cleantech R&D

Key challenges	Public sector/academia	Private sector
Financing	• **Insufficient public funding for cleantech R&D** (e.g. INR 5–6 Cr over 5 years to IITs) • **No dedicated national cleantech fund;** existing DST/CSIR grants lack sectoral targeting	**Limited investment from private sector:** • **Low R&D spend** (2–3% of revenue vs. ~6% global benchmark) • **Minimal VC/PE investment** (~3.7% of total VC / PE funding in cleantech in last 3 years)
Governance and policy	• **No central coordinating body** for cleantech R&D • **Fragmented initiatives** across ministries with **limited sector focus** • **Regulatory delays** hinder commercialization	• **Lack of industry-wide R&D coordination;** focus remains on imports and tech transfer • **Underutilized private labs** due to limited infrastructure sharing

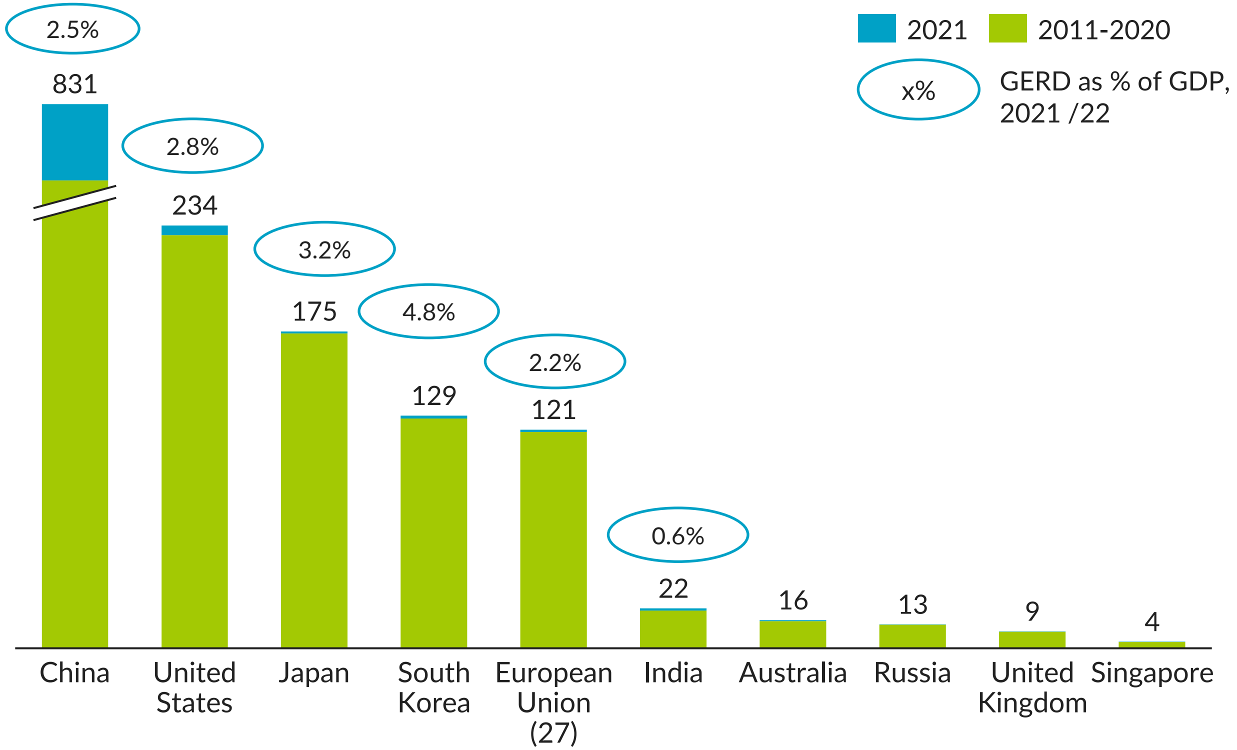
Source: Expert inputs; PIB, Ministry of Science & Technology, Efforts to Make 'Viksit Bharat' by 2047; Bloomberg (BNEF); EY Monthly PEVC Roundup 2025

Moreover, India's focus on climate tech innovation has remained relatively low and this needs to be addressed to achieve the required pace of indigenisation

While there is a growing trends of climate tech innovations in India, further acceleration is required; there exists a need to drive climate tech focused innovation

- Strong correlation between GERD and innovation; countries **investing 2-5% of GDP in R&D** have filed **~90% of RE patents globally**
- **Globally, education institutes (14-18% of revenue) and private companies (1.8 – 6.3% of revenue)** also invest heavily in R&D
- India's GERD has remained relatively low; there is also **limited investment from private companies** (2-3%)
- However, India has witnessed an increase in climate-tech startups; **investments in climate startups** increased by **33.87% CAGR** (2018-2023)
- India has also been **granted 22,000 patents** between 2016-2021

Gross Expenditure on R&D (GERD as % of GDP) and number of renewable energy, e-mobility and energy storage patents filed by country, 2011-2021, '000 patents



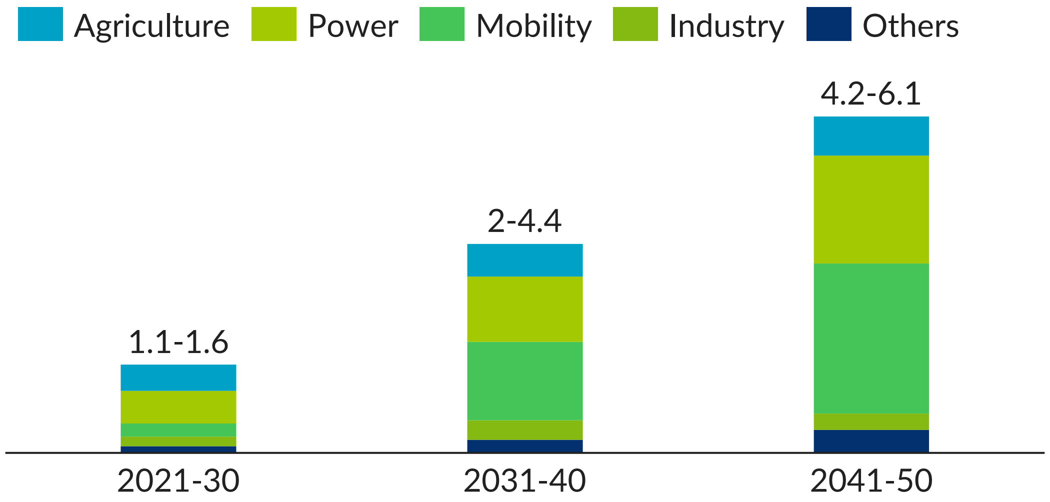
Beyond funding, India's cleantech R&D faces challenges like **weak tech commercialization, limited quality infrastructure** and **resource sharing**, and **lack of coordination among national R&D bodies** which also need to be addressed

Source: Department of Science and Technology (DST), Government of India, R&D Statistics at a Glance 2022-23

R&D would be an important step to meeting India's *Aatmanirbhar* and *Viksit Bharat* goals through indigenous innovation and reduced import dependence

Indigenous R&D could fuel import dependence reduction to ~50% by 2030 for cleantech sectors...

Estimated investment by decade for indigenous cleantech manufacturing for achieving net zero by 2070, USD Tn



If the **current import reliance continues**, **India will give ~70% (USD 5-8.5 Tn)** of this investment **to China and other countries for imports**

...Recent public and private sector efforts in R&D could support a cleantech R&D ecosystem to achieve this

Public finance

INR 1 lakh Cr

Research, Development and Innovation (RDI) Scheme to boost private sector R&D in "sunrise tech" including cleantech[1]

(Detailed ahead)

Government Institutional focus

Anusandhan National Research Foundation (ANRF)

established to support R&D growth; cleantech amongst priority sectors

Cleantech R&D Ecosystem

Private investment

Growing investments in R&D centers and private sector-academia collaborations in cleantech

Other countries and regions are already accelerating indigenous R&D efforts; **India must also build on internal tailwinds and seize this opportunity, potentially through ANRF**

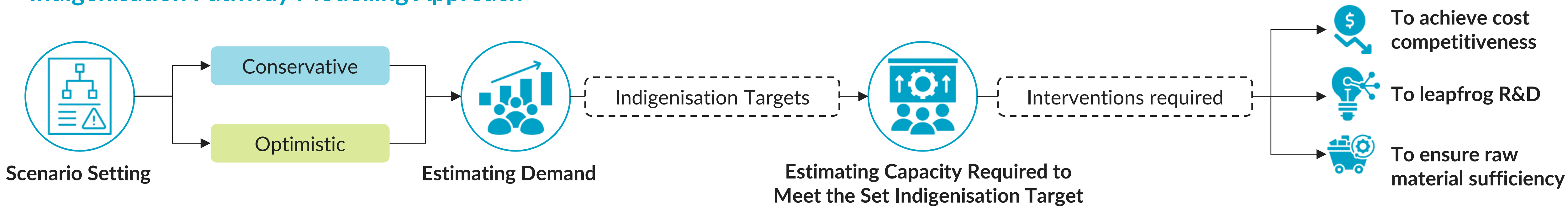
Source: (1) PIB, Union Budget 2024-25; Mahindra Rise; Hindustan Zinc

SECTION THREE

R&D AND INFRASTRUCTURE REQUIREMENTS FOR CLEANTECH MANUFACTURING

The cleantech indigenisation pathways have been built on two demand scenarios – conservative and optimistic – to identify potential pathways and key enablers to achieve sectoral indigenisation targets (1/2)

Indigenisation Pathway Modelling Approach

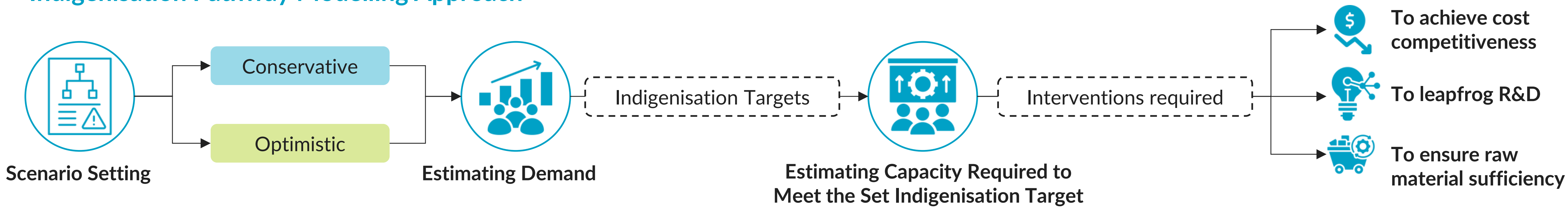


Scenario criteria	CONSERVATIVE SCENARIO			OPTIMISTIC SCENARIO		
	Solar	Wind	Battery	Solar	Wind	Battery
1 Government policy landscape		Upswing in tender activity, top states to meet RAP targets	Extension of ACC PLI and support for implementation		All states meet RAP targets; augmentation of grid at current pace	Extended support to battery manufacturers across value chain
2 Adoption Trajectory	Solar & hybrids meet **70%** of green H_2 energy demand **50%** off-grid & C&I adopt domestic modules	C&I levels expected to increase from current levels	**40 GWh** BESS by 2030 + additional for grid stability; **EV 30@30** to be achieved	Solar & hybrids meet **100%** of green H_2 energy demand **70%** of off-grid & C&I adopt domestic modules	Corporate shift to hybrid power accelerates to meet RE100 by 2030	Coverage of all additional VRE under 2-hour BESS; adoption of E2W/E3W beyond 30@30 goals
3 Export growth	**Africa**: Offer credit to 4 countries on use of Indian modules **US**: Deployment grows at 8% CAGR	**US/Europe/ME & Africa**: Existing share of 15% in global exports to these countries to be maintained		**Africa**: Offer credit to all countries on use of Indian modules **US**: Deployment grows at 10% CAGR	**US/Europe**: Existing share of 15% in global exports to be maintained **ME & Africa**: Increase in total share considered	

Source: MNRE, Physical progress; MNRE, Press release; : ISA, India EXIM bank ; PV Magazine, Industry experts (industry associations; Source: GWEC, Global Wind Report, 2025 report; Ministry of Heavy Industries, PM E-Drive Portal; CEA, National Electricity Plan Vol I; Company announcements; Industry experts; mec+ analysis; Dalberg analysis

The cleantech indigenisation pathways have been built on two demand scenarios – conservative and optimistic – to identify potential pathways and key enablers to achieve sectoral indigenisation targets (2/2)

Indigenisation Pathway Modelling Approach



Scenario criteria	CONSERVATIVE SCENARIO		OPTIMISTIC SCENARIO		
	E-mobility	Green Hydrogen	E-mobility	Green Hydrogen	Transmission
1 Government policy landscape	No additional subsidies on EVs beyond existing subsidies under PM E-DRIVE		Extension of subsidy schemes beyond 2026, especially for 2W, 3W, Bus and Trucks		*Demand for Transmission sector is **primarily government driven** and estimated to reach **6.5 lakh ckm by 2032***
2 Adoption Trajectory	Limited TCO[1] and product innovation – overall penetration[2] across vehicle segments expected to reach ~32% by 2030	Fertilizer sector – corresponds to tendered green ammonia capacity Refinery sector – 5% to 15% green H_2 blending in 2027-2030 for refiners with >50KTPA H2 consumption	Charging infra scale up, product innovation and financing mechanisms could enable ~48% penetration by 2030	Fertilizer sector - 100% import substitution of ammonia from 2027 Refinery sector – 5% to 30% green H_2 blending in 2027-2030 for refiners with >50KTPA H2 consumption	
3 Export growth		**EU, Japan, Singapore, South Korea, UK**: India could capture 10% of this market by 2030		**EU, Japan, Singapore, South Korea, UK**: India could capture 20% of this market	

(1) Total Cost of Ownership; (2) Penetration refers to % share of EVs in total annual vehicle sales; Sources: VAHAN Dashboard ; RMI, Niti Ayog, Harnessing Green Hydrogen, 2022; SECI, Clarification for setting up Production facilities for Green Hydrogen under SIGHT scheme, 2024; Bain, RMI, From Promise to Purchase: Unlocking India's Green Hydrogen Demand, 2025; MoP CEA, National Electricity Plan, Volume II – Transmission, 2024; Company announcements; Industry experts; Dalberg analysis

India could accelerate indigenous innovation from identification to prototyping and commercialization through an industry-academia-government collaborative approach

Co-ordination and representation from industry, academia, government to spearhead this effort and engage relevant stakeholders across various steps

Line ministries · Academia · Industry · (x) Detailed ahead

Research papers / TRL 1-2

1 Tech Identification
of 10-20 Cleantech innovations for each sector

TRL 3-4

2 Partnerships
With academia and industry for tech and knowledge transfer

3 Infra identification
For R&D infrastructure upgrades / setup required

4 Infra setup
Upgrading / setting up R&D infrastructure

TRL 4-5

5 Grants
in-line with focus innovations to accelerate prototyping

6 Prototyping
Enable accelerated prototyping for grant winners

TRL 6-7

7 Capital Access
Catalyze private capital, PE/VC participation

TRL 8+

8 Commercialization
Enable accelerated commercialization, industry tie-ups

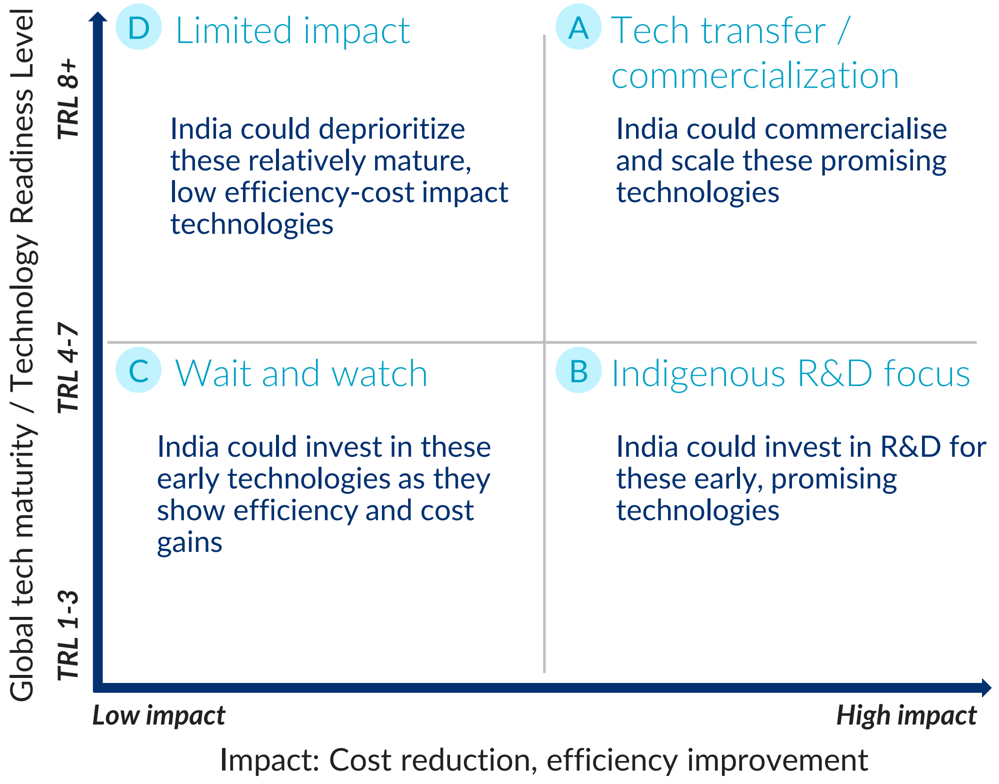
GoI funding support: concessional capital, equity, etc. through dedicated R&D fund

1 Identification and discoverability | It is critical to identify key technologies with inputs from relevant stakeholders for targeted R&D efforts and pathways to commercialisation

NON-EXHAUSTIVE

Technologies can be prioritized based on their impact potential and TRL levels globally to identify focus technologies for tech-transfer or indigenous R&D and innovation

Prioritisation methodology for technologies



Key Technologies in the R&D Ecosystem across sectors

- **Solar: Tech transfer/Commercialization**: POE encapsulants, busbar-less cells; **Indigenous R&D:** Nano-coatings, perovskite-silicon tandem cells
- **Battery: Tech transfer/Commercialization:** Solid polymer electrolytes, tabless electrode design, silicon-based anodes; **Indigenous R&D:** Sodium-ion batteries, lithium-sulphur batteries, solvent-based separation and bio-hydrometallurgy recycling
- **Wind: Tech transfer/Commercialization:** split-path gearboxes, spiral-welded & 3D-printed tall towers; **Indigenous R&D:** AI wake steering & farm control, self-healing polymer blade coatings, and wooden laminated veneer lumber (LVL) blades
- **E-mobility: Tech transfer/Commercialization:** Ultra-Fast DC Charging, Microchannel Heat exchangers, Synchronous Reluctance Motors, Phase Change Materials, Integrated Cooling Loops; **Indigenous R&D**: Ferrite-based Magnets, Pushbelt, Electronically Controlled CVT
- **Green Hydrogen: Tech transfer/Commercialization:** DOT™ bipolar plate coatings, Mixed Matrix membrane, PTE–CNF interlayers, biomass-to-hydrogen; **Indigenous R&D:** PVDF/PVDF-co-HFP membranes, laser-textured PTLs, high-entropy alloy catalysts
- **Transmission: Tech transfer/Commercialization:** Hybrid MMC (Modular Multilevel Converter), Clean Air + Vacuum GIS, Polymeric UHV Insulators (>800 kV): **Indigenous R&D:** DC Filter Elimination , Hybrid HVDC breaker, Advance MMCs (Modular Multilevel Converter)

Source: Spectrum Impact, ITRI

2

Partnerships | Dedicated top-down efforts for R&D on cleantech manufacturing could be supported through partnerships between industry, academia, government and Bharat Climate Forum

- **India's cleantech innovation landscape is characterised by fragmented ownership and coordination**
- R&D spans across DST, DBT, CSIR, MNRE, MeitY, MoP, MoE, etc., with the **lack of a unified body to set priorities or integrate efforts** in cleantech sectors
- Most R&D partnerships are **limited to government grants**, and **few involve deep co-development with industry** (e.g. Mahindra, Waaree–IIT Bombay)
- Partnership models rarely **incentivize risk sharing** or **IP commercialization** leading to limited private investment in scaling up new innovations
- **ANRF** is mandated under the DST to support cross-sectoral cleantech R&D and manage the allocated budget to help support prototype technologies

Proposed ecosystem model to help unify efforts and create concerted actions across academia, industry and government

Government

ANRF
Mandated to support cross-sectoral cleantech R&D

Government departments and ministry for R&D: DST, DBT, CSIR, TDB, MoE

Line ministries: MNRE, MOP, MHI, Ministry of Mines etc.

Core Working Group (under ANRF)
Line ministries and representatives from industry, academia, Bharat Climate Forum

Key responsibilities:
- Identify the **100-120 focus cleantech innovations for India** and support till commercialization
- Gather inputs from industry, academia and share recommendations
- Drive implementation of R&D policies, incentives and ensure commercialization of focus innovations

Academia

Indian Academia
Research institutions and R&D labs
- Identify R&D opportunities, partnerships
- Open access R&D infrastructure
- Drive concept to prototyping

Academia Coordination

Global Academia
Global academia, venture studios / R&D labs
- Knowledge and technology sharing
- Train the trainers

Private Sector
Industry, startups
- Increase R&D investment, infrastructure for identified innovations
- Accelerate prototyping to commercialization

Legend:
- Inputs and recommendations
- Policies implementation

R&D infrastructure | R&D infrastructure would need to be assessed and set up / upgraded with focus on select, high-quality open-access R&D labs driving public-private collaboration

Development and testing equipment upgrades and setups are required for prototyping to commercialization across focus sectors along with public-private institutional and financial support to develop the R&D ecosystem

Infrastructure Needs

Development Infrastructure

- **Pilot scale production lines:** E.g., Graphene production lines, alloy production units, membrane fabrication units, nanomaterial production units, catalyst production units, electrolyser stack assembly lines, coil winding/EV motor assembly lines
- **Sector-specific equipment:** E.g., Membrane synthesis, Magnetometers, superconducting magnets, sintering and quenching, CNC gear machines
- **Requisite labs:** E.g., Cryogenic chambers, efficiency-testing and materials research labs, chemical wet-lab, gas purity analyser

Testing Infrastructure

- **Characterization equipment:** E.g., for 2D materials, nanomaterials for cell and battery applications, for blade and gearbox defects, for motor/battery health
- **Testing equipment:** E.g., ElectrolySers testing, solar module testing, battery testing (including low humidity space), high-capacity wind tunnel, ocean technology platforms, battery cell simulators, large high-voltage halls and software grid simulators

Backbone services *(advanced digital, industry 4.0 tech)*

- Supercomputers
- Simulation software, digital twin, relevant AI models
- Efficient data management, Intellectual property management certification
- Assembly automation prototype

Key Insights

- Expand government-supported research centers and innovation hubs under the Ministry of Science and Technology (e.g., SATHI centers in IITs) as **open-access testbeds for cleantech,** accelerating collaboration and reducing R&D costs
- Channel capital expenditure to **upgrade testing facilities through existing specialized institutes** across different sectors (e.g., National institutes for Solar, Wind energies, Center for Automative Technology etc.)
- **Incentivize private sector** participation through fiscal incentives and by enabling **project-based access to incumbent-owned state-of-the-art labs**, while ensuring intellectual property protection
- **Broaden existing global science and technology partnerships** such as with the EU, Germany and the US to support joint research and pilot projects in emerging clean technologies
- **Coordinate centralized procurement** of critical equipment and infrastructure to optimise costs and standardize capabilities across institutions

Source: Spectrum Impact, ITRI

4A

Capital Access | Ensuring financing availability for MSMEs across R&D technology development lifecycle is a critical gap due to acute capital shortages during prototype and early commercialization stages

TRL Band	Funding Opportunities Currently Available	Core Financing Gaps / Barriers
TRL 1–3 Idea to lab proof	• DST, CSIR, academic grants • Startup India Seed Fund • NIDHI-PRAYAS micro-grants • BIRAC • Founder capital	• Non-academic founders struggle to access public R&D pools • High funding requirement for setting up prototyping infrastructure (climate tech hardware requires fab, battery testing, power electronics facilities) • Almost no angel/VC appetite for pre-prototype hardware • Grants cover only a fraction of lab & test-rig costs
TRL 4–6 Prototype to pilot in a relevant environment	• DST grants (e.g. EVolutionS grants) • Technology Development Board's soft loans • Limited angel / climate-tech seed funds • MNRE Pilot & Demonstration Schemes • MeitY SAMRIDH	• Prototyping, tooling & certification need funding • Public support capped, equity investors still see high-tech market risk • Bank credit unavailable without collateral or revenues
TRL 7–9 Pilot plant to commercial scale	• Series A/B venture equity & venture debt- Bank/SIDBI loans; credit-guarantee schemes (CGTMSE, CGSS) • Central/state capex subsidies • IREDA project financing	• Capex exceeds most MSME balance sheets • PLI eligibility sidelines MSMEs • Working-capital crunch as OEM payment cycles stretch • Banks remain risk-averse despite guarantees

Chronically underserved

Source: CPI, Roadmap for an Automotive Component Technology Upgradation Facility, 2025

4B

Capital Access | A mix of funding instruments and interventions will be necessary for MSMEs to meet localisation targets and invest in the commercialization of technology prototypes (1/2)

TRL Band	Recommended interventions	Details
TRL 1–3 Idea to lab proof	**Dedicated innovation fund**	A pooled pre-seed innovation fund blending public R&D grants with corporate CSR/VC catalytic capital
	Challenge-based innovation prizes	Modeled on global ARPA-E/EIC calls, prize-based competitions for MSME innovations for various cleantech sectors. Similar to China's **"Little Giants"** program which certifies high-tech SMEs for preferential loans, subsidies, and research partnerships – demonstrating how early-stage public support plus recognition can unlock MSME innovation
	Co-funded industry–academia challenge programs	Use joint government–industry funding models (e.g., IMPRINT) to launch challenge calls that deepen collaboration between MSMEs, academia, and global partners, accelerating early-stage cleantech innovation
TRL 4–6 Prototype to pilot in a relevant environment	**Blended-finance bridge funds**	Structures that pair concessional debt or first-loss guarantees with private VC.
	Extended EvolutionS-type programs	Larger ticket sizes (₹2–5 crore vs. ₹50 lakh) through state incubators, tied to performance milestones
	OEM-backed pilot funds	Co-financing pools where OEMs and Tier-1s share pilot risk with MSMEs, ensuring order visibility
	Enhance utilization of equity fund from SIDBI	Simplify access and broaden eligibility for MSMEs while building readiness programs for equity investments to ensure fuller fund utilization

Source: CPI, Roadmap for an Automotive Component Technology Upgradation Facility, 2025

4B

Capital Access | A mix of funding instruments and interventions will be necessary for MSMEs to meet localisation targets and invest in the commercialization of technology prototypes (2/2)

TRL Band	Recommended interventions	Details
TRL 7–9 Pilot plant to commercial scale	**MSME-tier PLI**	Lower eligibility thresholds (e.g., ₹50 crore revenue instead of ₹500 crore) and milestone-based disbursal
	Interest subvention funds	Dedicated concessional loan window reducing MSME borrowing costs from ~12–17% down to 7–8%
	Transition funds with co-investment	Government-backed cornerstone investors catalyzing family offices/DFIs into MSME tech-upgrade funds

Source: CPI, Roadmap for an Automotive Component Technology Upgradation Facility, 2025

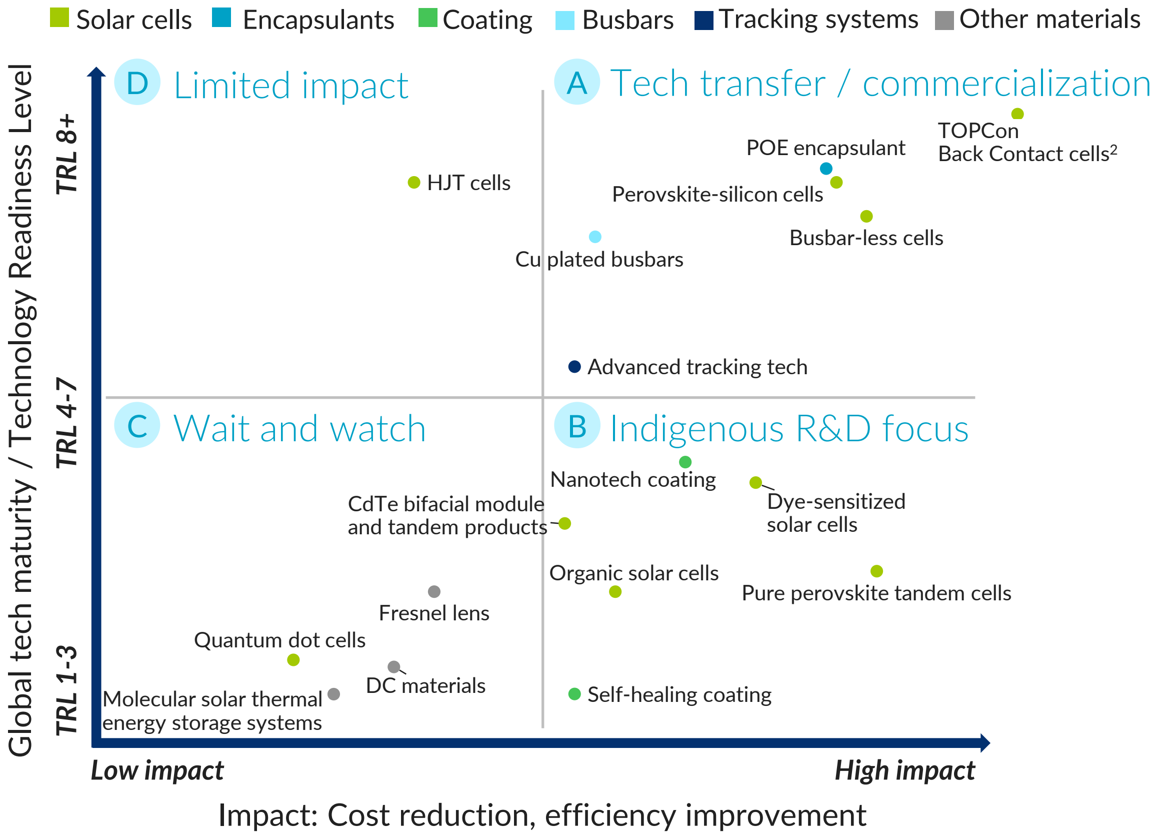
SECTION FOUR

ANNEX: SECTORAL R&D DEEP DIVES

Solar sector: Identification and discoverability | It is critical to identify key solar technologies with inputs from relevant stakeholders for targeted R&D efforts and pathways to commercialisation

NON-EXHAUSTIVE

Focus R&D and innovation technologies[1]: Solar



Key Insights on R&D Ecosystem

- Most high-impact solar technologies, like **POE encapsulant and busbar-less cells**, have been piloted internationally and present strong opportunities for improved efficiency and cost reduction in India's solar manufacturing
- **Perovskite–silicon tandem cells** offer 24.5% efficiency and low predicted LCOE, with early R&D underway in India (e.g., IIT Roorkee)
- Indigenous innovation efforts focus on materials such as **nano-coatings and self-healing coatings** but many components have high import dependence
- **Integrate** these prioritized solar technologies **into solar R&D infrastructure planning**, ensuring alignment with TRL- stage requirements
- **Increase solar cell efficiency threshold in ALMM to 22%[3]** from 2027 onwards to encourage to encourage accelerated commercialization of indigenous solar R&D prototyping

(1) Already mature and commercial technology in India (e.g. TOPCon) not featured here; displayed tech in early R&D/ lab pilot stages; (2) Combination of TOPCon and IBC, i.e. (Interdigited Back Contact) cell architecture type; (3) Cell efficiency for Utility scale solar for c-Si modules compared to 20% today (target efficiency for other applications, e.g. rooftop/ off-grid could be adjusted in-line)

Source: Sansad and PIB reports; US Department of Energy; NREL; IEA; World Economic Forum; PV Magazine, PV Tech, Mercom India; Energetica India Magazine; Fraunhofer Institute for Solar Energy Systems ISE; Company websites and news reports

Solar sector: R&D infrastructure | India could invest INR 750-910 Cr across 14-17 R&D labs to upgrade current solar R&D labs, establish new facilities, and ensure needed human resource for efficient lab operations

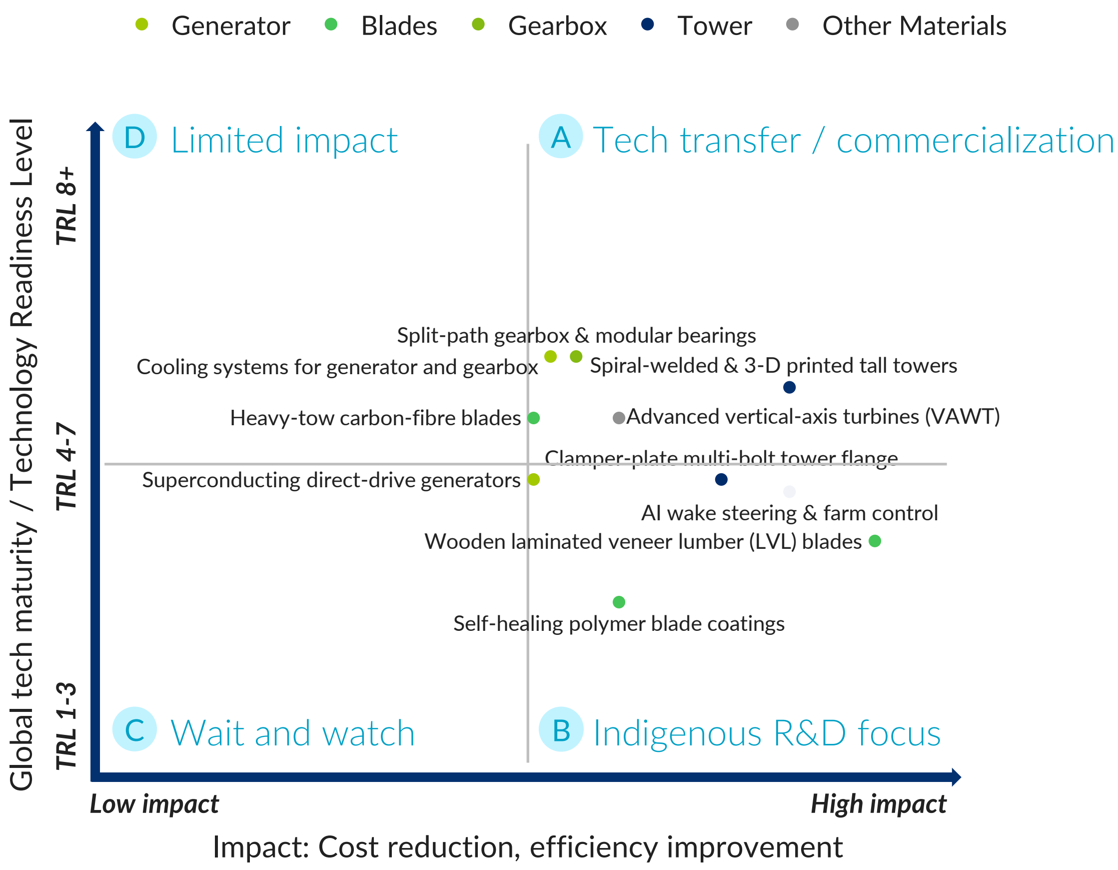
	DEVELOPMENT LABS	TESTING LABS
Number of labs	**10-12 development labs** *5-6 each for existing and new labs*	**4-5 testing labs** *About 4 regional testing labs under 1 central facility*
Cost per lab	**INR 750-900 Cr** *INR 50 Cr/ lab for upgrades; INR 100 Cr/ lab for new setup*	**INR 4-10 Cr** *INR 1-2 Cr for upgrades/ new setup*
Prospective existing labs for upgrade	*IIT Bombay lab* *IIT Delhi lab* *IIEST lab* International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) AN AUTONOMOUS R&D CENTRE OF DEPARTMENT OF SCIENCE & TECHNOLOGY, GOVERNMENT OF INDIA *DST lab*	**Central testing facility** *NISE lab*
Machinery needs	• Material synthesis and deposition machines • Device fabrication equipment • Coating machines	• Material testing equipment • Efficacy testing machines (including lab, field, and commercial testing)
Manpower and support needs	**Advanced training** for new equipment/ materials; leveraging researchers' pre-existing tech know-how	• **PPP-driven lab management team** for max. capacity utilization, avoid delays, and develop industry connect • **Market needs assessment** of upcoming tech trends to inform relevant research

Source: Academia and industry experts

Wind sector: Identification and discoverability | It is critical to identify key wind initiatives with inputs from relevant stakeholders for targeted R&D efforts and pathways to commercialisation

NON-EXHAUSTIVE

Focus R&D and innovation technologies[1]: Wind



Key Insights on the R&D Ecosystem

- **Top 5 –10 technologies across gearbox, bearings and blade coatings etc.** could be focused on for commercialization / tech-transfer and indigenous R&D
- Most high-impact wind technologies, such as **split-path gearboxes and spiral-welded & 3D-printed tall towers,** have been piloted internationally and offer significant potential for cost reduction, reliability, and efficiency gains if commercialized and localised in India
- Indigenous R&D focus can be placed on **AI wake steering & farm control, self-healing polymer blade coatings, and wooden laminated veneer lumber (LVL) blades**
- There is a need to ensure **quality standards for raw material and subcomponents** are aligned across the industry
- **Integrate** these prioritized wind technologies **into wind R&D infrastructure planning**, ensuring alignment with TRL- stage requirements
- Most required R&D initiatives for India are quite mature in developed economies, so poised for **commercialization**

(1) Technologies considered in this initiatives are based on stakeholder inputs and wind supply chain assessment for onshore wind conducted by mec+

Source: MEC Analysis; Stakeholder consultations across wind supply chain, IEA; Mercom India; Energetica India Magazine; Company websites and news reports

Wind sector: R&D Infrastructure | India could invest INR 450-500 Cr across 10-12 R&D labs to upgrade current wind R&D labs, establish new facilities, and ensure needed human resource for efficient lab operations (2/2)

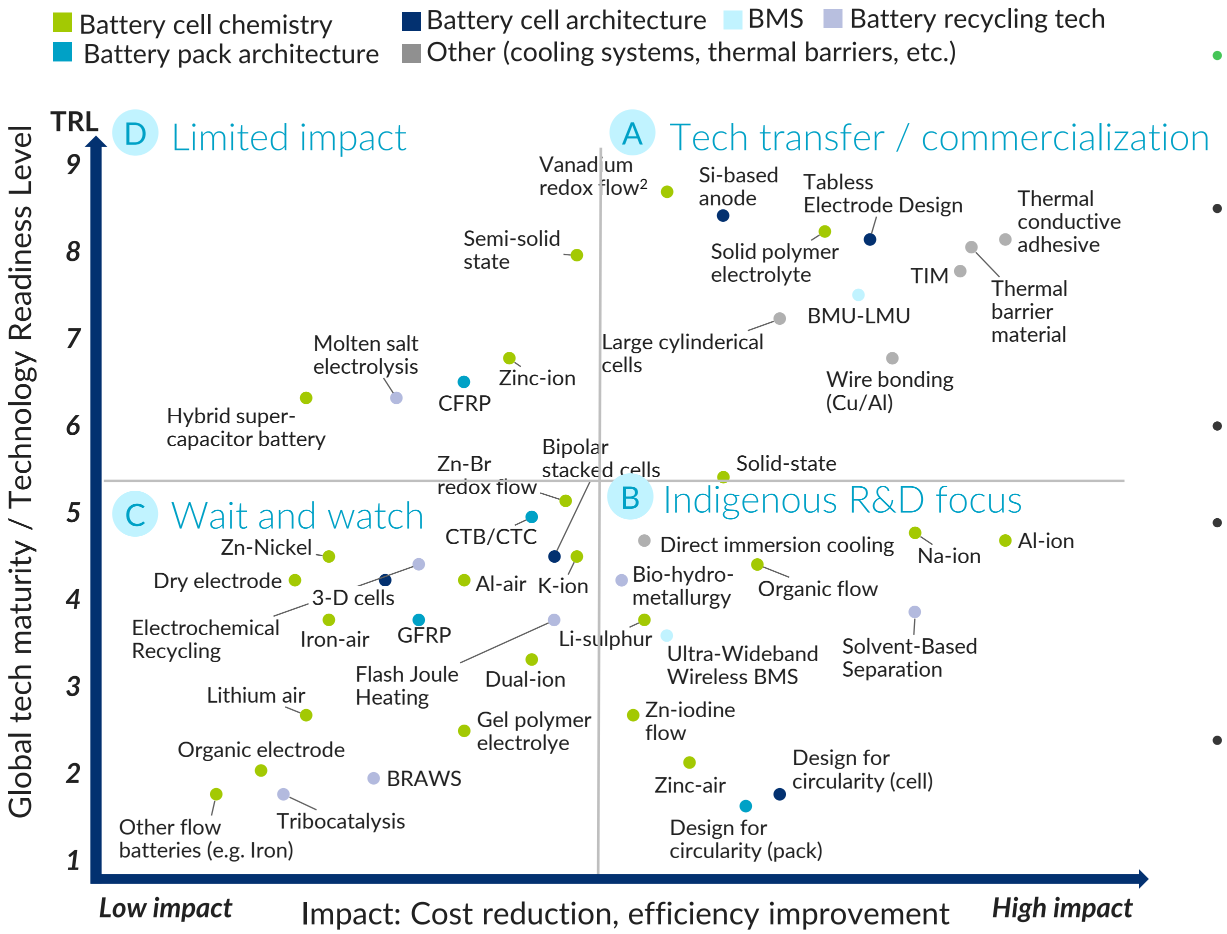
	DEVELOPMENT LABS	TESTING LABS
Number of labs	**5-6 development labs** *~2-3 each for existing and new labs*	**4-5 testing labs** *About 4 regional testing labs under 1 central facility*
Cost per lab	**INR 400-450 Cr** *INR 50 Cr/ lab for upgrades; INR 100 Cr/ lab for new setup*	**INR 4-10 Cr** *INR 1-2 Cr for upgrades/ new setup*
Prospective existing labs for upgrade	• *To be evaluated*	**Central testing facility** नीवे NIWE *NIWE lab*
Machinery needs	• Device fabrication equipment • Coating machines • CNC gear machines • Heat treatment and metallurgical analysis	• Material testing equipment • Efficacy testing machines (including Full-scale blade test rigs, vibration rigs, gearbox benches, fatigue/lifecycle rigs and others)
Manpower and support needs	**Advanced training** for new equipment/ materials; leveraging researchers' pre-existing tech know-how	• **PPP-driven lab management team** for max. capacity utilization, avoid delays, and develop industry connect • **Market needs assessment** of upcoming tech trends to inform relevant research

Source: Academia and industry experts

Battery sector: Identification and discoverability | It is critical to identify key battery technologies with inputs from relevant stakeholders for targeted R&D efforts and pathways to commercialisation

NON-EXHAUSTIVE

Focus R&D and innovation technologies: Battery [1]



Key Insights on R&D ecosystem

- **Top 10-20 technologies across battery cell chemistry, architecture and cooling systems etc.** could be focused on for commercialization / tech-transfer and indigenous R&D
- Most high-potential battery technologies such as **solid polymer electrolyte batteries, thermal adhesives, and tabless electrode design** have been piloted and demonstrated in global markets and can unlock significant cost and efficiency improvements
- Manufacturing scale-up and supply-chain localisation for more mature technologies in India are still at early stages
- Indigenous innovations such as **sodium-ion batteries, Lithium-sulphur, Zinc-air batteries, direct immersion cooling, and solvent-based separation** are at lower TRLs, but hold potential for commercialization and are seeing early-stage pilots in India (e.g. IIT Madras and Hindustan Zinc)
- India can **leverage existing research parks and technology partnerships** to adapt and commercialize these solutions (e.g. IIT Delhi/Madras Research Parks, Social Alpha Energy Lab)

(1) Already mature and commercial technology in India (e.g. LFP) not featured; (2) Only for BESS applications; Zn-Br: Zinc-Bromine; CFRP: Carbon Fiber Reinforced Polymers; GRPF: Glass Fiber Polypropylene; K-ion: Potassium-ion; Si: Silicon; Na: Sodium; Zn: Zinc; TIM: Thermal Interface Material; Li: Lithium; CTB: Cell-to-Body; CTC: Cell-to-chassis; BRAWS: Battery Recycling and Water Splitting

Source: PV Magazine, Saur Energy, Battery tech online, NITI Aayog, Future Battery Lab, Company websites, Startup websites, Research lab websites, The EV Report, Sodium battery hub, Technology Review, Science Direct, IITs, expert inputs

Battery sector: R&D infrastructure | India could invest INR 1,200–2,400 Cr across 12-16 R&D labs to upgrade current battery R&D labs, establish new facilities, and ensure needed personnel and efficient lab operations

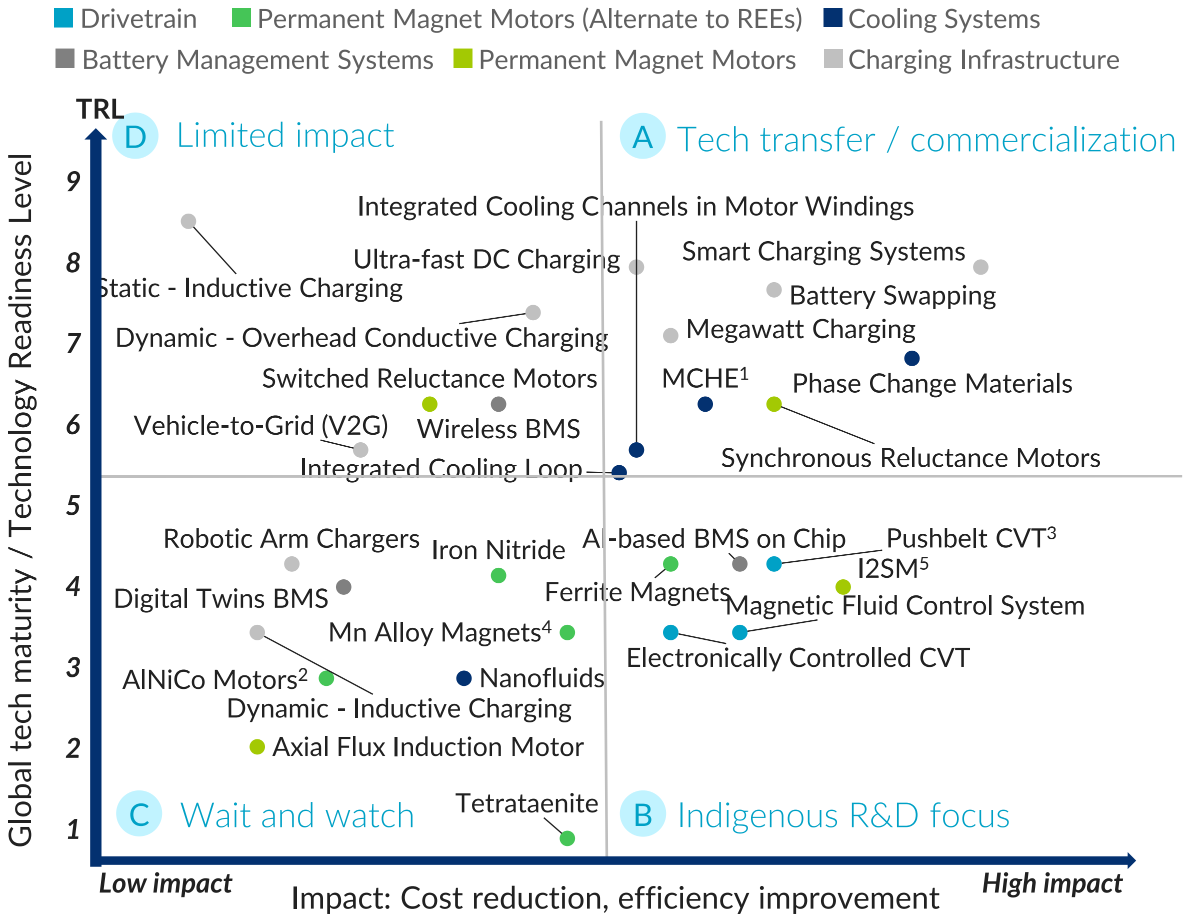
	Battery technology development and testing labs	Battery recycling technology development and testing labs
Number of labs	**10-12 development and testing labs** *7-8 small labs (TRL 4-5) and 3-4 large labs (TRL 5-8)*	**2-4 development and testing labs** *Upgrades to 1-2 current labs; set up of 1-2 new labs*
Cost of labs	**INR 1,100-2,000 Cr** *INR 50-100 Cr/ small lab; INR 250-300 Cr/ large lab for set up/ upgrades*	**INR 100-400 Cr** *INR 50-100 Cr/ lab for upgrades/ new setup*
Prospective existing infrastructure for upgrade	FITT – Foundation For Innovation And Technology Transfer **IIT Delhi Research Park:** CoE and Incubation Centre iitm research park – Bringing unlike minds together **IIT Madras Research Park:** Labs, testing facilities, incubation centres, etc. SOCIAL alpha – CLEAN ENERGY INTERNATIONAL INCUBATION CENTRE **Social Alpha:** Energy lab	iitm research park – Bringing unlike minds together **IIT Madras Research Park:** R&D labs, testing facilities, incubation centres, etc.
Machinery needs	***High precision equipment*** *suited for R&D which is* ***customizable and agnostic*** *across different chemistries and materials:* • Material R&D and chemical wet-lab equipment • Coating and calendaring machines • Stacking/ winding machines • Battery testers	• Material R&D and chemical wet-lab equipment • Battery grinders, shredders and crushers • Air flow separators • Battery testers
Manpower and support needs	• **Trained manpower** with ability to use advanced equipment (separate upskilling for current researchers) • **Independent management team** reporting to own Board vs. public/ private sector researchers to ensure maximum utilization, efficient operations • **Market needs assessment** of upcoming tech trends to inform relevant research	

Source: Academia and industry experts

E-mobility sector: Identification and discoverability | Build industry-academia-government collaboration to support prototyping to commercialization for 10-20 indigenous innovations across the EV value chain

NON-EXHAUSTIVE

Focus R&D and innovation technologies: E-mobility



Key Insights on the R&D Ecosystem

- **Top 10-20 technologies across charging infrastructure, drivetrains, motors, etc.** could be focused on for commercialization / tech-transfer and indigenous R&D
- Most high-impact e-mobility technologies, like **Ultra-Fast DC Charging, Megawatt Charging Systems, synchronous reluctance motors, phase change materials**, have been piloted internationally and present immediate opportunities for **greater efficiency** than conventional variants
- Indigenous R&D should focus on technologies at lower TRLs such as **Ferrite Magnets** since they offer comparable power efficiency and **In-Rotor Inductively Excited Synchronous Motors** since they demonstrate greater efficiency than PMSMs
- Other indigenous technology focus includes **Pushbelt and Electronically Controlled CVT** which offer higher transmission efficiency than conventional gear systems
- **Integrate these prioritized e-mobility technologies into anchor R&D labs** (e.g., IIT Delhi's CART, IIT Madras Research Park), ensuring infrastructure is aligned with the TRL stage of key drivetrain, battery, and charging innovations

(1) MCHE: Microchannel Heat Exchanger; (2) AlNiCo: Aluminium-Nickel-Cobalt; (3) CVT: Continuously Variable Transmission; (4) Mn: Manganese; (5) I2SM: In Rotor Inductively Excited Synchronous Motors; (6) For tech identification and funding; (7) Upgrading existing/ building new; Source: Academia and industry experts; US Small Business Administration, Annual Report, 2022

E-mobility sector: R&D infrastructure | India could invest INR 2,800-5,000 Cr across 6-8 R&D labs to upgrade current E-mobility R&D labs, establish new facilities, and ensure needed manpower and efficient lab operations

	DEVELOPMENT LABS	TESTING LABS
Number of labs	**4-6 development labs** *3-4 COEs (motors, power electronics, systems integration and 1-2 innovation centers*	**2 new testing labs** *Upgrades to 1-2 current labs (e.g., ICAT labs to test innovation and compliance perspective); set up of 1-2 new labs for Pilot scale testing*
Cost of labs	**INR 1,700-2,800 Cr**	**INR 1,100-2,200 Cr** *Investment across innovation, compliance and pilot testing labs* *Prioritize investment for **innovation testing** labs to carry more technologies to pilot stages*
Prospective existing infrastructure for upgrade	**IIT Delhi:** Centre for Automotive Research and Tribology **IIT Madras:** Centre of Excellence in Advanced Automotive Research	Central testing facility **DHI CoE for E-mobility under Automotive Research Association of India** **ICAT:** Labs, testing facilities, etc.

***High precision equipment** suited for R&D which is **customizable and agnostic** across different EV and battery segments*

	DEVELOPMENT LABS	TESTING LABS
Machinery needs	• Material R&D and chemical wet-lab equipment • Rotor magnet insertion equipment, SMT[1] lines • Battery cell simulators, current and voltage measuring tools	• Material testing equipment • Efficacy testing machines (including lab, field, and commercial testing)

Manpower and support needs

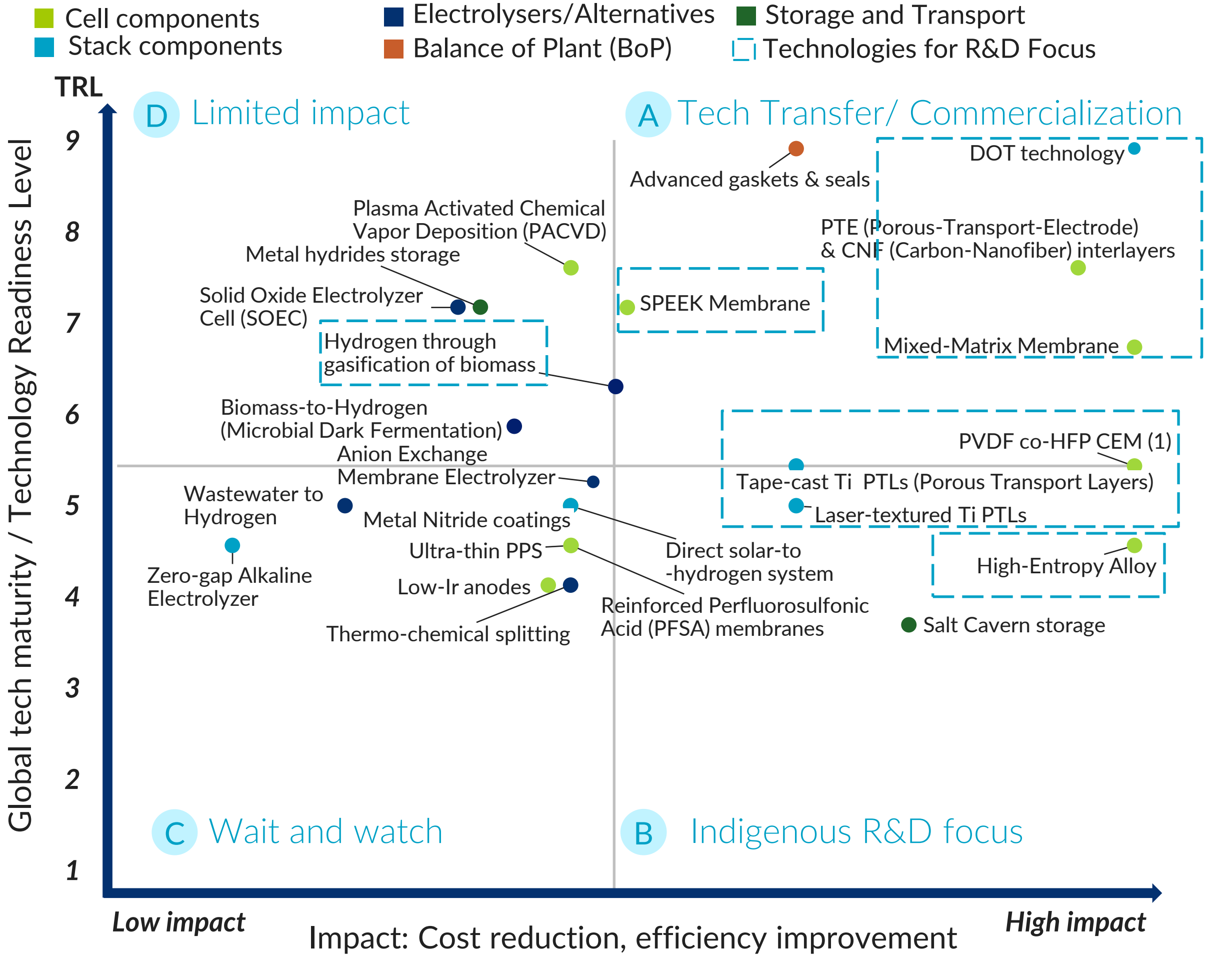
- **Trained manpower** with ability to use advanced equipment (separate upskilling for current researchers)
- **Independent management team** reporting to own Board vs. public/ private sector researchers to ensure maximum utilization, efficient operations
- **Market needs assessment** of upcoming tech trends to inform relevant research

(1) Surface Mount Technology used to assemble Printed Circuit Boards used in Battery Management Systems and Power electronics
Source: Academia and industry experts

Green hydrogen sector: Identification and discoverability | Focus on cost-saving tech transfer, scaling up proven stack innovations, and building R&D depth in indigenous alternative catalysts and electrolysers

NON-EXHAUSTIVE

Focus R&D and innovation technologies: Green Hydrogen



Key Insights on the R&D Ecosystem

- **Tech transfer** should be focused on **innovative membrane** and **bipolar plate coating technologies**
  - Most high potential technologies have been **tested and piloted outside India** with strong potential for **cost reduction and efficiency improvements** in electrolyser performance
  - **Large-scale manufacturing infrastructure** is still under development
  - India can leverage **existing research labs** and partnerships with global companies (i.e. Fraunhofer, Ionbond) to commercialize for local contexts
- Other avenues such as **alternative alloy catalysts** and **porous transport layers** should be an **indigenous R&D focus** to reduce imports
  - Components usually have **high import dependence** on critical minerals for PGM catalysts and coatings
  - Innovations are **nascent**, but hold potential for commercialization given **their efficiency and reduced critical mineral use**
- Beyond electrolyser cell and stack manufacturing, there are ongoing R&D efforts in **alternative ways to produce and store hydrogen**
  - **Biomass to hydrogen** is proven as an alternative to electrolysis, but the reliable supply of biomass at scale is still a challenge
  - SOEC and AEM electrolysers are not as relevant efficiency-wise – India is **focusing on PEM and Alkaline electrolysers**

Note: 1. PVDF-co-HFP copolymer based polymeric cation exchange membranes;
Source: Dalberg Analysis

Green hydrogen sector: R&D infrastructure | India could invest INR 250 - 300 Cr to upgrade green hydrogen R&D labs, establish new facilities, and ensure needed manpower and efficient lab operations

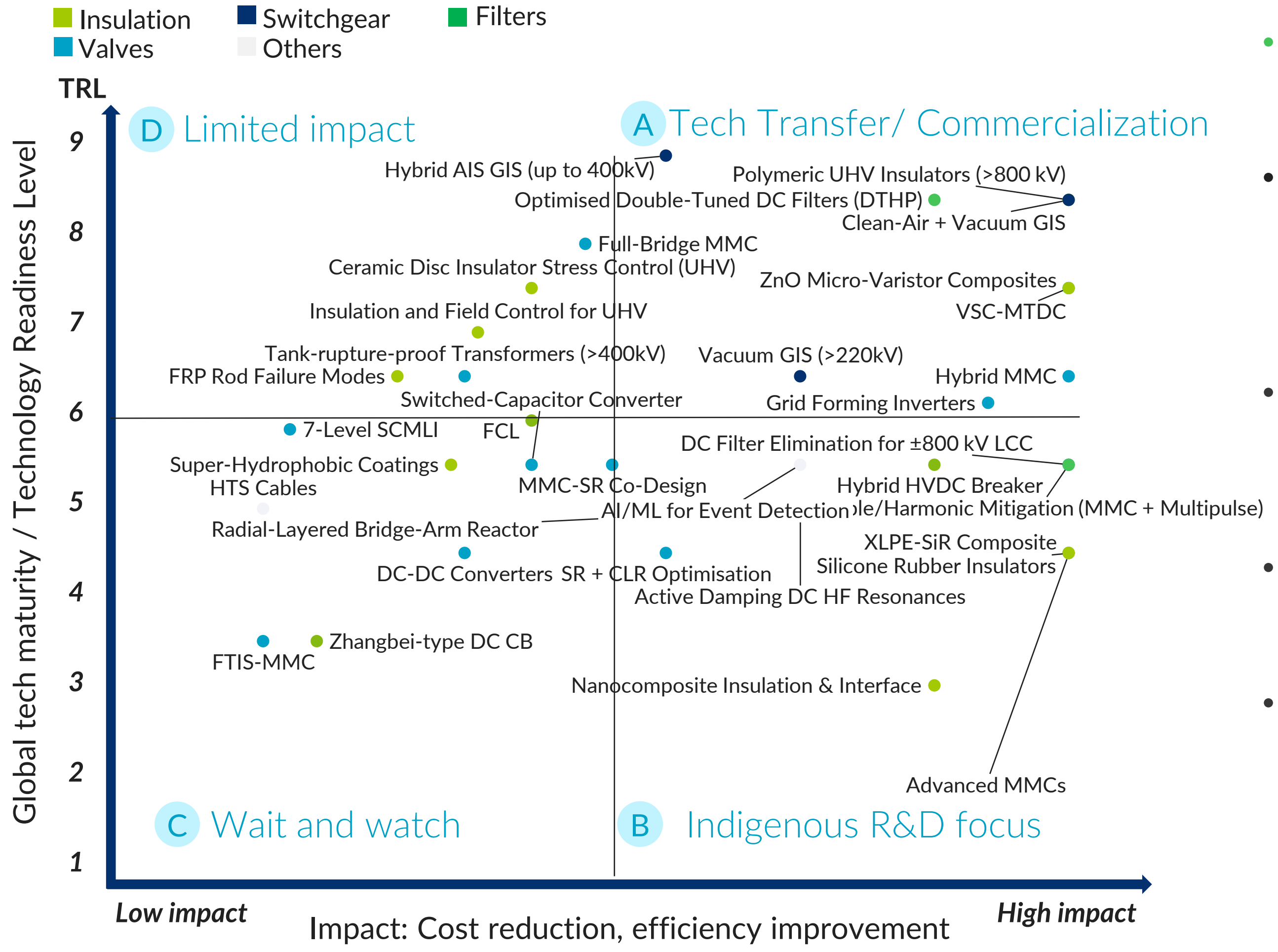
	DEVELOPMENT LABS	TESTING LABS
Number of labs	**1-2 development labs** *Additional national mission-mode labs*	**4-5 testing labs** *Standardized integrated testing across components*
Cost per lab	**INR 10 Cr** *Upgrading development facility*	**INR 50 Cr** *MW-scale testing facility*
Prospective existing labs for upgrade	NCPRE *IIT Bombay lab* *IISc* International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) AN AUTONOMOUS R&D CENTRE OF DEPARTMENT OF SCIENCE & TECHNOLOGY, GOVERNMENT OF INDIA *DST lab*	**Central testing facility** NISE *NISE lab*
Machinery needs	• Material synthesis and deposition machines • Coating machines • Casting machines	• Material testing equipment • Efficacy testing machines (including lab, field, and commercial testing)
Manpower and support needs	• **Advanced training** for new equipment/ materials; leveraging researchers' pre-existing tech know-how	• **Professional external lab management team** for max. capacity utilization and access for all stakeholders • **Efficiency benchmarks for industry and standardized testing criteria** to inform relevant research

Source: Academia and industry experts

Transmission sector: Identification and discoverability | Build an R&D ecosystem with industry-academia-government collaboration, supporting prototyping to commercialization for 10-20 indigenous innovations

NON-EXHAUSTIVE

Focus R&D and innovation technologies: Transmission



Key Insights on the R&D Ecosystem

- **Top 10-20 technologies across valves, insulation, switchgear, etc. for HVDC** could be focused on for commercialization / tech-transfer and indigenous R&D
- Most high potential technologies for tech transfer such as **Hybrid MMC (Modular Multilevel Converter), Clean Air + Vacuum GIS, Polymeric UHV Insulators (>800 kV)** have been piloted internationally and offer higher efficiency impacts across different components
- Indigenous R&D focus could be placed on **DC Filter Elimination , Hybrid HVDC breaker, Advance MMCs (Modular Multilevel Converter)** since they are at lower TRLs and offer efficiency and cost reduction
- These components are **mostly still import dependent** and can be commercialized/ tech transferred through **technology partnerships**
- India can **leverage existing research parks and labs to adapt and commercialize these solutions** for Indian context (e.g. IISc/IIT Power Electronics, BHEL Small & Large Test Bays)

Transmission sector: R&D infrastructure | India could invest INR 1,000-1,300 Cr to upgrade & consolidate core HV transmission R&D facilities, expand testing capabilities, and create a coordinated framework for innovation

Number of labs

2-3 System Studies Labs	₹ 100-110 Cr
1-2 Equipment Design & Small Test Bays	₹ 160-300 Cr
1 Central Large Hardware Test Facility with Accreditation Center	₹ 730-840 Cr

Total cost of labs

₹ 1,000-1,300 Cr

Represents **0.7-0.9%** of estimated national HVDC expenditure from 2022-2032

Prospective existing labs for upgrade

- *IISc/IITs Power Electronics*
- *PGCIL System Simulation*
- *BHEL Small & Large Test Bays*
- *CPRI Accreditation Facility*

Machinery needs

- Real-time software grid simulators
- Small HV test bench
- Rigs for power electronics & cooling systems
- Large HV halls for full-scale testing
- High-current & short-circuit stations
- Dedicated synthetic test circuits
- Heat, humidity, corrosion, vibration chambers
- Benches for protection & communication relays

Manpower and support needs

- Offices to manage technology transfer
- Templates for licensing, MoUs & IP protection
- Focused programs to attract & train young engineers to address the current talent gap in universities and labs

Source: Academia and industry experts

Thank you!

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