How Can India Align Its Clean Energy Innovations with Its Ambitions?

An Assessment of Public RD&D Investments and Activities

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This report accompanies the launch of *India's Clean Energy RD&D Tracker,* an evolving public database designed to improve transparency around India's publicly funded clean energy research and innovation ecosystem.

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Image: iStock

Executive Summary

India's clean energy ambitions now extend well beyond installing renewable generation capacity. Across solar, storage, hydrogen, transport, energy efficiency, and carbon capture, the stated objective is increasingly to make these technologies in India, competitively and at scale. This, however, depends on the knowledge of production processes, materials, systems integration and scale-up – knowledge that has to be developed or acquired. Public research, development, and demonstration (RD&D) is how a country accumulates that knowledge, and it is where industrial ambition either becomes domestic capability or does not. Whether India's public RD&D is building the knowledge and capabilities its clean energy and industrial ambitions require is the question this study sets out to answer.

Until now, that system has been hard to see as a whole. Funding is spread across multiple ministries and agencies, each disclosing its own projects separately through annual reports and sanctioned-project lists, with no central register that consolidates them into a view of the public research base. This report assembles that view through a database of 1,359 publicly funded clean energy RD&D projects active between 2019 and 2024, representing approximately INR 1,443 crore (USD 151 million[1]) in declared funding across over 90 institutions.



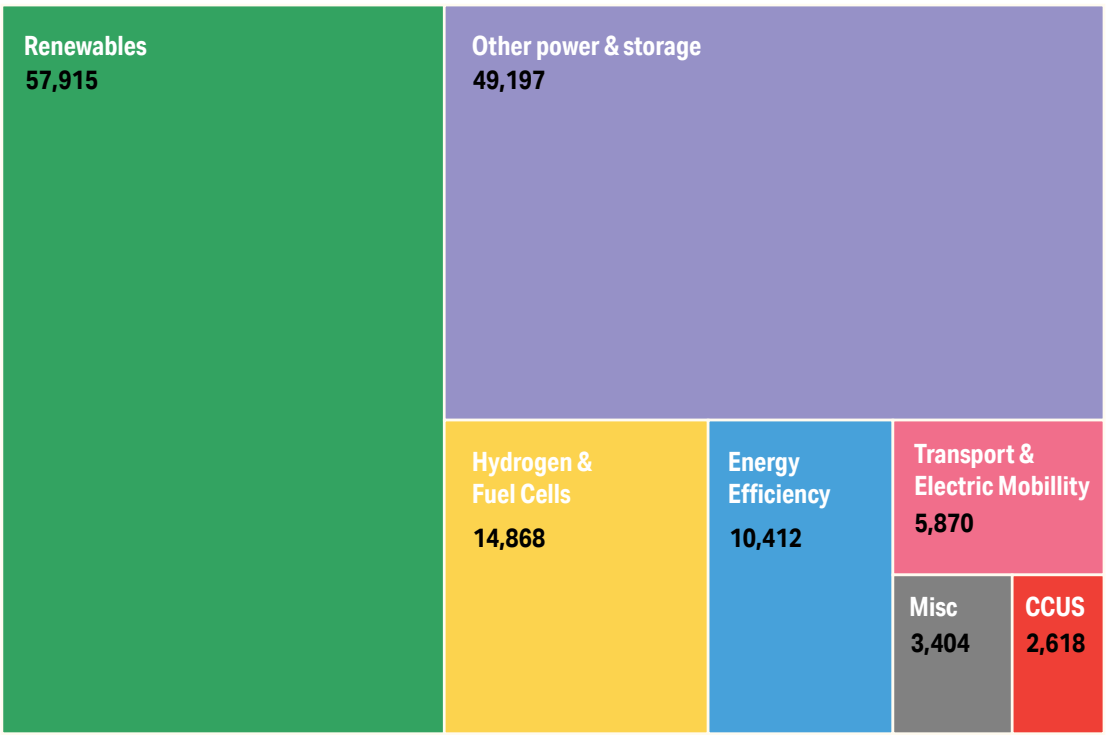
The analysis examines how research effort is distributed across technologies, what kinds of innovation the portfolio supports, and whether that pattern aligns with India's broader clean energy, industrial, and climate objectives. Since the database is assembled from public disclosures, it represents a large sample rather than a complete census of India's public clean energy RD&D. Projects are classified across six technology areas (renewables; other power and storage; hydrogen and fuel cells; transport and electric mobility; energy efficiency; and carbon capture, utilisation and storage), and coded according to whether they are incremental or radical, and whether they focus on products or production processes.

What India's clean energy RD&D portfolio contains

Effort is concentrated, more so by funding than by project count. Among the mapped projects, renewables account for 421 projects and INR 580 crore (USD 61 million), followed by power and storage at 333 projects and INR 492 crore (USD 52 million). Together they absorb about three-quarters of declared spending. Within renewables, solar photovoltaics alone take 234 projects and INR 401 crore (USD 42 million), more than the hydrogen, energy efficiency, transport, and CCUS categories combined.

1 USD equivalents use INR 95.55 per USD and are rounded

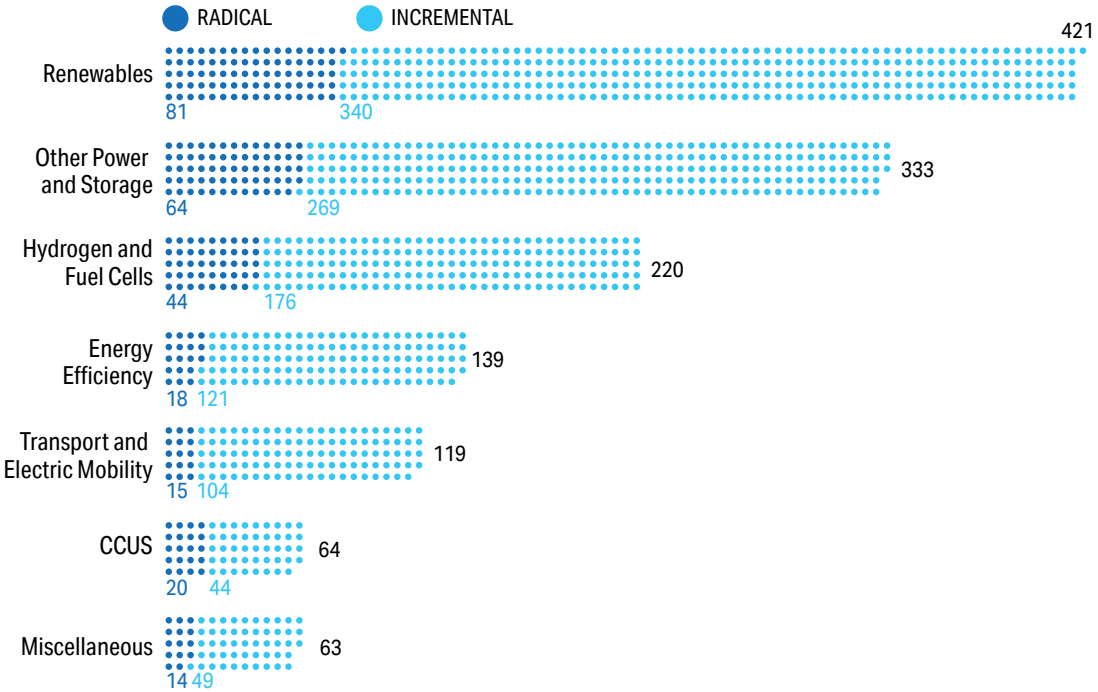
Fig. 1 Declared funding by technology category



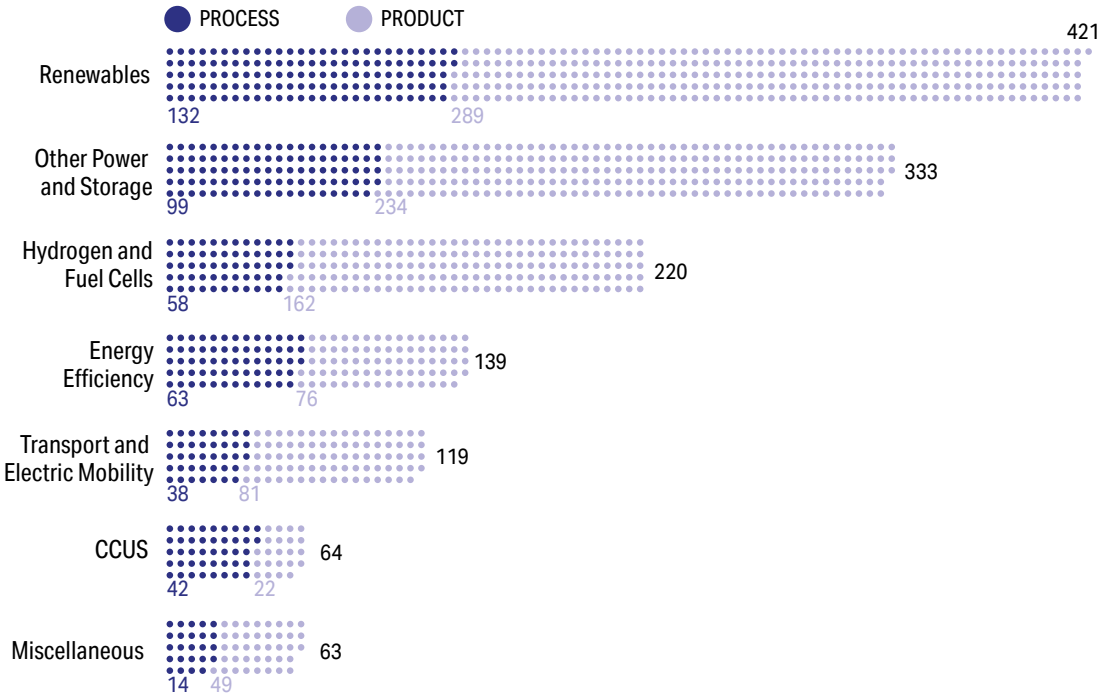
Source: Authors' analysis

The research is overwhelmingly incremental and product-focused. Across the mapped projects, 81% improve, adapt, or optimise technologies already in commercial use, while 67% focus on products. This pattern is consistent across renewables, storage, and hydrogen.

Fig. 2 How does the degree and type of innovation vary by clean energy sector?



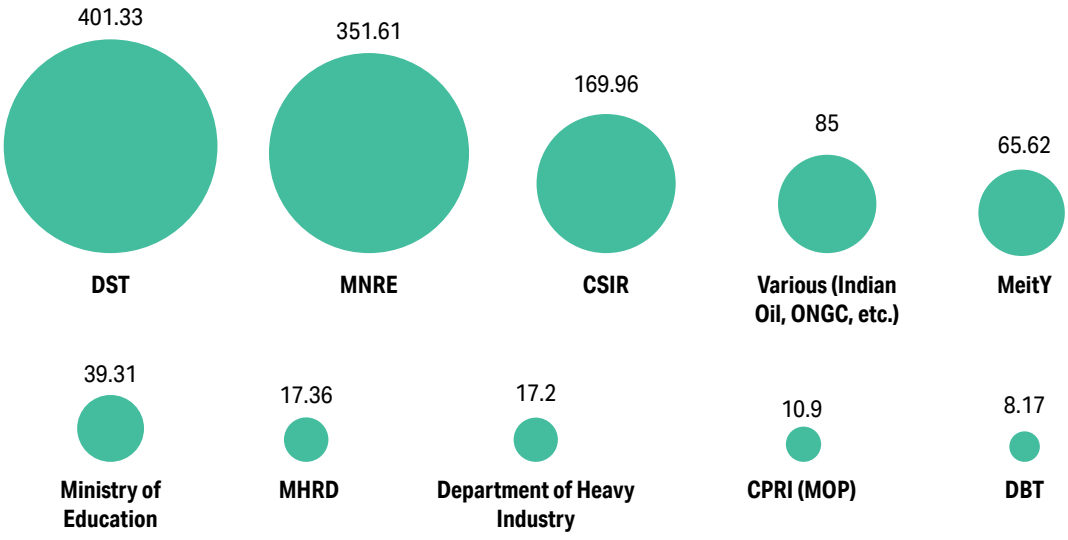
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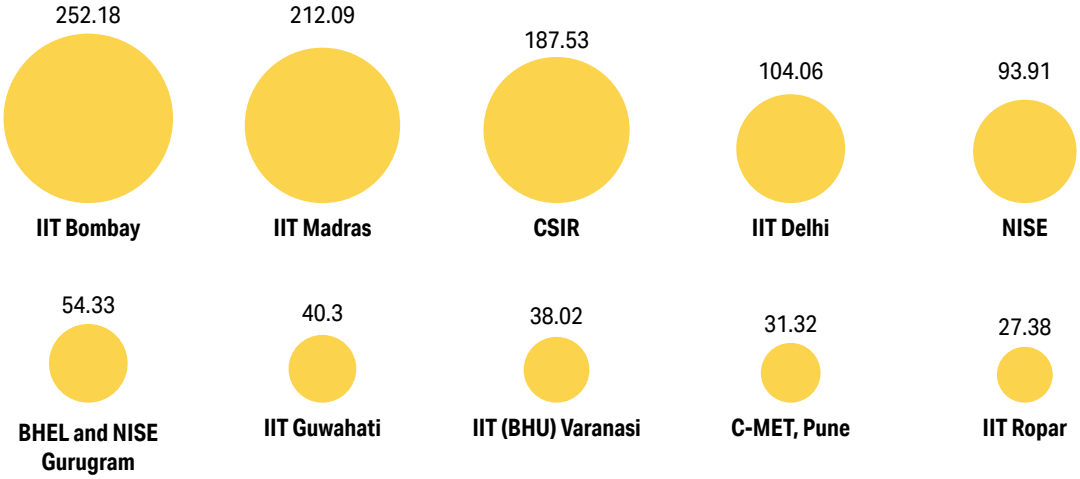
Source: Authors' analysis

Funding is fragmented, while projects are small and uniform in scale across technology categories. The Department of Science and Technology (DST) accounts for more than half of the mapped projects through numerous investigator-led grants, whereas the Ministry of New and Renewable Energy (MNRE) supports relatively few but much larger programmes. Across the portfolio, 68% of projects with declared budgets receive less than INR 50 lakh (USD 52,000) and median project size varies only between INR 33 lakh and INR 39 lakh (USD 35,000–41,000) across technology categories, suggesting that different types of research are often supported through similar funding instruments. The top 20 institutions account for close to 70% of all projects despite research activity spanning over 90 institutions.

Fig. 3 Who funds clean energy RD&D in India and who receives funding?



Source: Authors' analysis



Source: Authors' analysis

Why this matters

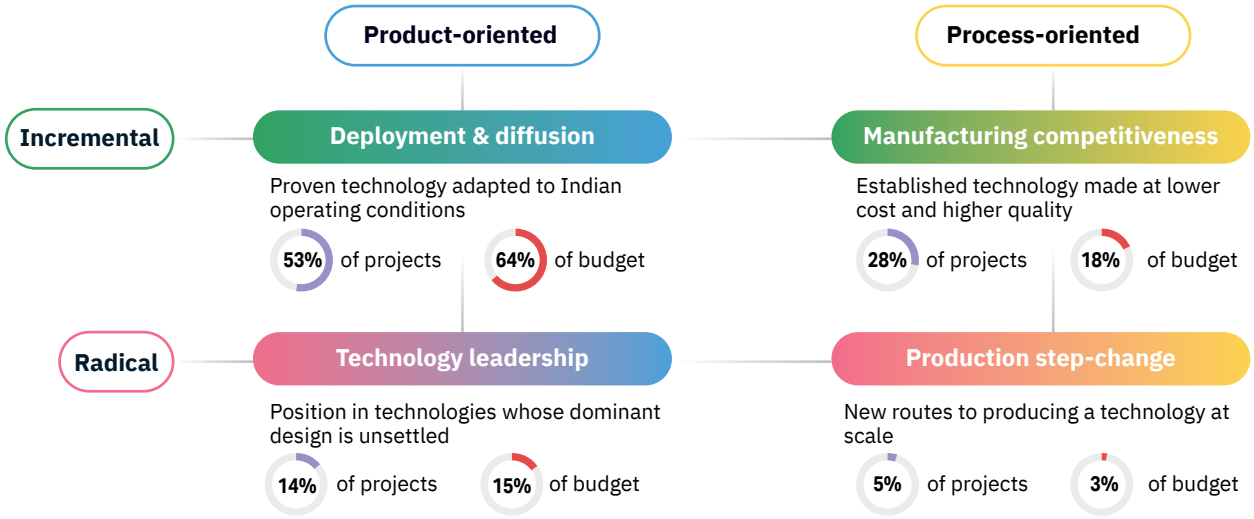
India's transition is occurring under conditions that imported technologies do not automatically accommodate: high ambient temperatures, dust and humidity, price-sensitive demand, constrained material and equipment supply, and a skills base still being built. Research focused on adapting technologies to local conditions – battery thermal management, module degradation and low-cost charging – can generate real near-term returns. Viewed through that lens, the portfolio is well aligned with India's deployment needs.

Deployment, however, is no longer India's only objective. Manufacturing capability has become an explicit national priority. Product innovation determines what is made; process innovation determines how it is produced efficiently, consistently, and at competitive cost. Yet the mapped public RD&D portfolio remains weighted heavily towards product innovation. Two caveats are important. No published benchmark was identified for the appropriate balance between product and process innovation in public clean energy RD&D, and much process innovation occurs within private firms that are outside the scope of this database. The findings therefore relate to the composition of India's public research portfolio rather than to national innovation capability as a whole.

The funding architecture reinforces this pattern. Uniform grant sizes may be appropriate for investigator-led research but are less well suited to pilot manufacturing, production engineering, demonstration, and scale-up, where manufacturing capabilities are often developed. Different capability objectives therefore appear to require different funding instruments.

The central finding is not that India's RD&D priorities are necessarily wrong. Rather, the balance between deployment, manufacturing capability, and technology leadership appears to have emerged from many independent funding decisions, without an explicit portfolio-level strategy visible in the public record.

Fig. 4 Where public RD&D effort sits: projects and budget by strategic objective



Source: Authors classification and analysis

What follows

State the intended balance. As India's clean energy policy increasingly adopts an industrial policy orientation, RD&D strategies should articulate capability objectives alongside technology priorities, making explicit what public investment is expected to contribute to deployment, manufacturing competitiveness, and technology leadership.

Monitor the portfolio, not only the individual project. Portfolio-level monitoring should complement project-level evaluation, allowing policymakers and funders to assess whether aggregate investment remains aligned with evolving national objectives.

Differentiate funding instruments. Different stages of innovation require different scales, time horizons, and institutional arrangements. Broadening the mix of funding instruments is likely to address important gaps more directly than increasing the overall budget alone.

Treat process innovation as a strategic objective in its own right. Work on production methods, manufacturing equipment, quality control, and pilot-scale validation sits closer to industrial production than conventional laboratory research. Supporting these capabilities is likely to require stronger collaboration between public research institutions and industry.

What this analysis cannot show

The dataset is assembled from publicly available disclosures and should be understood as an evolving resource rather than a complete census of India's public clean energy RD&D. Budget information is unavailable for around 16% of projects, start years for 39%, and private-sector RD&D is not captured. Institutional reporting also tends to emphasise laboratory research, meaning prototype development, pilot testing, and industry collaboration are likely underrepresented. The classification of projects by innovation type is also inherently interpretive, particularly where project descriptions are limited.

1 Introduction

India's clean energy transition has scaled rapidly over the past decade, with deployment outpacing investments in RD&D and domestic manufacturing capabilities. Renewable energy capacity rose from roughly 76 GW in 2014 to over 290 GW (including large hydro) by August 2026, with solar alone exceeding 160 GW (MNRE 2026). More than half of installed electricity capacity now comes from non-fossil sources (CEA 2026), and recent policy updates have further raised ambition. India's updated NDC for 2031–2035, submitted in March 2026, targets 60% non-fossil electricity capacity and a 47% reduction in emissions intensity of GDP from 2005 levels (Government of India 2026).

The transition is no longer confined to electricity generation. The National Green Hydrogen Mission, the Production Linked Incentive (PLI) scheme for Advanced Chemistry Cell (ACC) battery storage (the ACC PLI scheme), and transport electrification targets extend the transition into fuels, storage, industry, and mobility. These programmes have also helped frame clean energy not only as a climate imperative, but as a pillar of industrial competitiveness, export potential, and employment generation.

Deployment came first.

For much of the past decade, policy focused on adding renewable capacity as rapidly and cost-effectively as possible. Competitive auctions drove rapid expansion, but they also reinforced dependence on imported technologies by rewarding the lowest-cost supplier regardless of where equipment was produced (Narassimhan 2025). Attempts to strengthen domestic manufacturing through domestic content requirements often sat uneasily alongside procurement frameworks that favoured imports (Narassimhan 2025; Gulia et al. 2023).

Over time, this approach has slowly shifted. Recent policy frameworks have placed greater emphasis on domestic manufacturing, with deployment increasingly linked to manufacturing through instruments such as tariffs, approved manufacturer mandates, and PLIs (Government of India 2025b). Yet these interventions sit largely within industrial policy rather than power-sector planning, and the extent to which they are coordinated with the public research system is not apparent from the public record.

Timing matters.

India's manufacturing push has emerged comparatively late, at a point when global manufacturing ecosystems, particularly in solar PV and batteries, are already highly consolidated, with established cost advantages, supply chain integration, and technological leadership concentrated in a few countries. India's solar module manufacturing base, initially confined to assembly of imported cells, had expanded to approximately 120 GW of module capacity and 29 GW of cell capacity by mid-2025, driven by customs duties, approved manufacturer mandates, and PLIs (Sharma et al. 2025). Local content requirements on government procurement have gradually pushed manufacturers to deepen value-chain participation. However, the ACC PLI scheme points to the limitations of this strategy. As of October 2025, the scheme, which was designed to establish 50 GWh of domestic battery cell manufacturing, had commissioned only 1.4 GWh, or 2.8% of its target, with zero incentives

RD&D builds the knowledge base that makes industrial policy productive.

disbursed and domestic dependence on imported battery cells remaining close to 100% (Sharma et al. 2026).

Analyses of India's clean energy manufacturing point to several constraints, including continued reliance on imports for upstream solar components such as polysilicon and wafers, and for production equipment (Gulia et al. 2023; Sharma et al. 2025), and limited domestic supply of battery cell materials (NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility 2022). These challenges point to a gap between the scale of India's manufacturing ambitions and the depth of domestic technological knowledge underpinning them.

This is the context in which public RD&D becomes strategically important.

Unlike deployment subsidies or manufacturing incentives, RD&D builds the knowledge base that makes industrial policy productive (Bell and Figueiredo 2012; Zhang et al. 2021). It determines whether domestic institutions accumulate expertise in design, process engineering, materials science, and system integration, or remain dependent on imported technology and know-how (Meckling et al. 2022; Zhang et al. 2021). Private firms often underinvest in such activities because gestation periods are long and returns uncertain, particularly in early-stage research and demonstration. Public RD&D can fill this gap, supporting capability development that markets alone are unlikely to provide (Mazzucato and Semieniuk 2017). In India, it can also support the adaptation of global technologies to local conditions.

The spillovers of well-directed public RD&D extend beyond the technologies themselves. Countries that have built competitive clean energy industries – Germany in wind, China across the solar value chain – have done so through sustained alignment between research systems, manufacturing incentives, and deployment policy (Nahm 2021). Public RD&D builds engineering capabilities, creates intellectual property, and reduces structural dependence on foreign technology and know-how (Nahm 2021). For India, these spillovers could be substantial given its large engineering base, diverse operating conditions, and scale of deployment.

The question is therefore not simply how much India spends on clean energy RD&D but whether limited clean energy RD&D resources are directed towards the technologies and capabilities that matter most for India's long-term energy, industrial, and climate objectives. The range of technologies demanding public research support has expanded significantly, from solar and wind to storage chemistries, hydrogen value chains, carbon capture, and grid digitalisation. These technologies differ in their maturity, their alignment with Indian industrial capability, and the feasibility of building competitive domestic positions for them within realistic timeframes. Spreading limited resources across all of them can produce breadth without depth, and scientific activity without industrial consequence. Yet in the absence of explicit choices about concentration and sequencing, public RD&D portfolios tend to evolve reactively, shaped by institutional inertia, the priorities of dominant funding agencies, and the distribution of faculty research interests rather than by deliberate alignment with industrial strategy.

Drawing on a mapping of 1,359 publicly funded clean energy RD&D projects active between 2019 and 2024, this study asks whether India's public clean energy RD&D system is building the technological and industrial capabilities the country's clean energy transition and industrial ambitions require. To answer this, the report assesses how resources are distributed across technology domains; what types of innovation are being supported; and how the portfolio relates to India's broader clean energy, industrial, and climate policy priorities.

Spreading limited resources across all of them can produce breadth without depth, and scientific activity without industrial consequence.

The report proceeds as follows. Section 2 sets out how the database was assembled, its coverage and its limitations. Section 3 describes the portfolio, examining funding patterns, institutional participation and research activity across technology areas. Section 4 interprets those patterns, asking what they imply about the orientation of India's public RD&D system and where tensions emerge between research investment, industrial policy and manufacturing ambition. Section 5 concludes with the implications for public RD&D policy.



Image: iStock

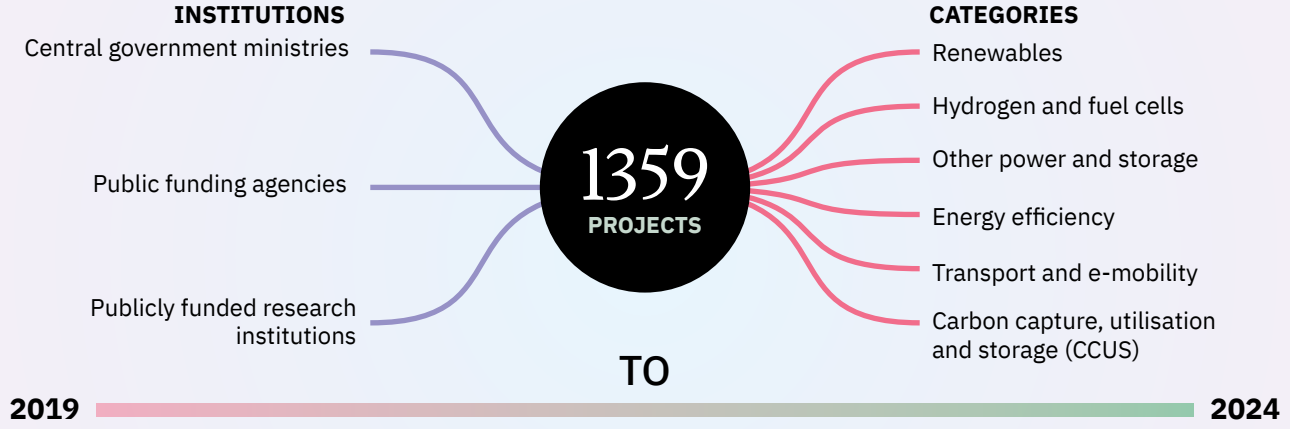
2 Methodology

This report is based on a structured mapping of publicly funded clean energy RD&D activities in India through systematic desk research. The database covers 1,359 projects undertaken by central government ministries, public funding agencies, and publicly-funded research institutions over the period 2019–2024 across six technology categories: renewables, hydrogen and fuel cells, other power and storage,[2] energy efficiency, transport and electric mobility, and carbon capture, utilisation and storage (CCUS). The study selected these categories to reflect India's priorities and to allow comparability with classifications used in the IEA RD&D Database (IEA 2025b), with two main differences: transport and e-mobility is treated as a separate category, and nuclear energy and fossil fuel RD&D other than CCUS fall outside the scope of this study.

The authors included projects where the stated research objective (as represented in the project title) fell within the scope of clean energy RD&D and excluded those with indirect or unclear links to energy applications. In cases where project titles were ambiguous and supporting information was not publicly available, projects were excluded rather than included. This conservative approach reduces the risk of including unrelated projects but is likely to understate the true scale of India's public clean energy RD&D activity, particularly for interdisciplinary research whose energy application is not explicit.

The authors then classified projects by nature of innovation and type of innovation (Table 2). Incremental innovation refers to projects that improve, adapt, or optimise components or performance within an established technological trajectory; radical innovation refers to projects pursuing materially different technical approaches, such as

Fig. 5 Scope of the database



The full project-level database is also available as an interactive tracker at sustainablefutures.org

Source: Authors compilation

2 Other power and storage includes electric power conversion, electricity transmission and distribution, and energy storage.

Table 1: Data sources

Source type	Examples
Research institutions	Indian Institutes of Technology (IITs), National Institutes of Technology (NITs), Indian Institutes of Information Technology (IIITs), Council of Scientific and Industrial Research (CSIR) laboratories, the Indian Institute of Science (IISc), the National Institute of Solar Energy (NISE), the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), the Central Power Research Institute (CPRI), and other autonomous research centres
Funding agencies	Department of Science and Technology (DST); Ministry of New and Renewable Energy (MNRE); Ministry of Electronics and Information Technology (MeitY); Ministry of Power (MoP); Council of Scientific and Industrial Research (CSIR); Anusandhan National Research Foundation (ANRF), among others.
Documents reviewed	Annual reports, project databases, institutional websites, project disclosures, mission documents, funding announcements

Source: Authors' compilation

Table 2: Classification framework

Dimension	Categories	Basis for classification
Technology	Renewables, hydrogen & fuel cells, other power & storage, transport & electric mobility, energy efficiency, CCUS	Primary technology focus inferred from project title and available description
Nature of innovation	Incremental or radical	Degree of novelty relative to existing technologies
Type of innovation	Product or process	Whether the project focused primarily on products/components or production/manufacturing processes

Source: Authors' analysis

new materials, architectures, or production pathways, whose feasibility or dominant design is not yet established (see Section 3.1 for further discussion). Product-oriented projects focus on the technology itself: its materials, components, design, or performance. Process-oriented projects focus on how the technology is made, including manufacturing methods, production equipment, quality control, and scale-up. These classifications were interpretive, based on available project titles and objectives, and should be read as such.

Limitations

The database and subsequent analysis are subject to certain limitations.

1. Institutional reporting is uneven: Some publicly funded institutions do not release annual reports, publish them irregularly, or make only summary versions available. Projects at these institutions are captured only where they appear in a funder's disclosure.
2. Where reports exist, the level of detail varies: Some institutions list every sanctioned project with title, principal investigator, funder, and budget. Others report only aggregate research spending, or list projects without budgets. The dataset reflects what was available.
3. Budget data and start years are incomplete: Budget and start year information is unavailable for approximately 16% and 39% of projects, respectively. For budgets, where reported, figures represent sanctioned amounts rather than audited spending and are not inflation-adjusted.
4. Private-sector research is not captured: Private companies rarely disclose research publicly. This database therefore represents only the public research system. This is a significant

gap since the private sector accounts for approximately half of national R&D expenditure (Ministry of Science and Technology 2026). Extending coverage to private research is a priority for future work.

5. Demonstration and industry-linked work may be undercounted: Institutional annual reports tend to emphasise laboratory research and report prototype development, pilot testing, and industry collaboration less consistently, even where these activities exist.
6. Funding agency and institutional records are not fully aligned: Funding agencies do not consistently publish project-level information identifying recipient institutions, while institutional reports do not always specify funding sources. Consequently, funding allocations cannot always be reconciled with institution-level research activities.
7. Multi-institution projects present reconciliation challenges: Collaborative projects sometimes appear separately in each participating institution's records. The study consolidated obvious duplicates, but institution-level counts may not perfectly reconcile with project totals.

The dataset thus represents an initial effort to systematically compile India's public clean energy RD&D activities and should be understood as iterative and likely to evolve as reporting improves and additional projects and institutions are identified.



Image: iStock

3 India's RD&D Portfolio

Sections 3.1 to 3.7 describe what the portfolio contains: which technologies receive attention, at what scale, and what kind of research activity they involve. Each technology section identifies where the composition of research effort diverges from what the technology or the policy objective appears to require.

3.1 Aggregate findings

India's publicly funded clean energy RD&D portfolio, as documented in this report, comprises 1,359 projects, initiated or active between 2019 and 2024, with a total declared budget of approximately INR 1,443 crore (USD 151 million). The portfolio spans the report's six technology categories – Renewables, Other Power and Storage, Energy Efficiency, Transport and E-mobility, Hydrogen and Fuel Cells, and CCUS – and draws on research conducted across over 90 institutions funded by a range of central government agencies. The analysis focuses on three dimensions that are particularly relevant for understanding the structure of public RD&D systems: where research effort is concentrated, how it is funded and by whom, and what kinds of innovation activity the portfolio contains. Together, these provide a basis for assessing how India's public RD&D system is currently organised.

Distribution of research effort across technology areas

By project count, effort is spread widely: Renewables leads at 421 projects, with Other Power and Storage at 333 and Hydrogen and Fuel Cells at 220.

Solar PV accounts for 234 of 421 renewables projects and roughly two-thirds of the category's budget, leaving wind, bioenergy, hydro, and ocean and tidal energy with little relative to their roles in India's energy system. Battery technologies take 128 of 333 storage projects. Fuel cell work dominates hydrogen at 87 projects, ahead of the 43 on electrolysis and catalysis. A miscellaneous category holds 63 projects, covering cross-cutting work in low-carbon industry and materials, waste-to-energy and thermal recovery, and general energy systems research that does not map cleanly onto the six primary categories.

By funding, concentration is sharper. Solar PV alone accounts for INR 401 crore (USD 42 million), more than the Hydrogen, Energy Efficiency, Transport and CCUS categories combined.

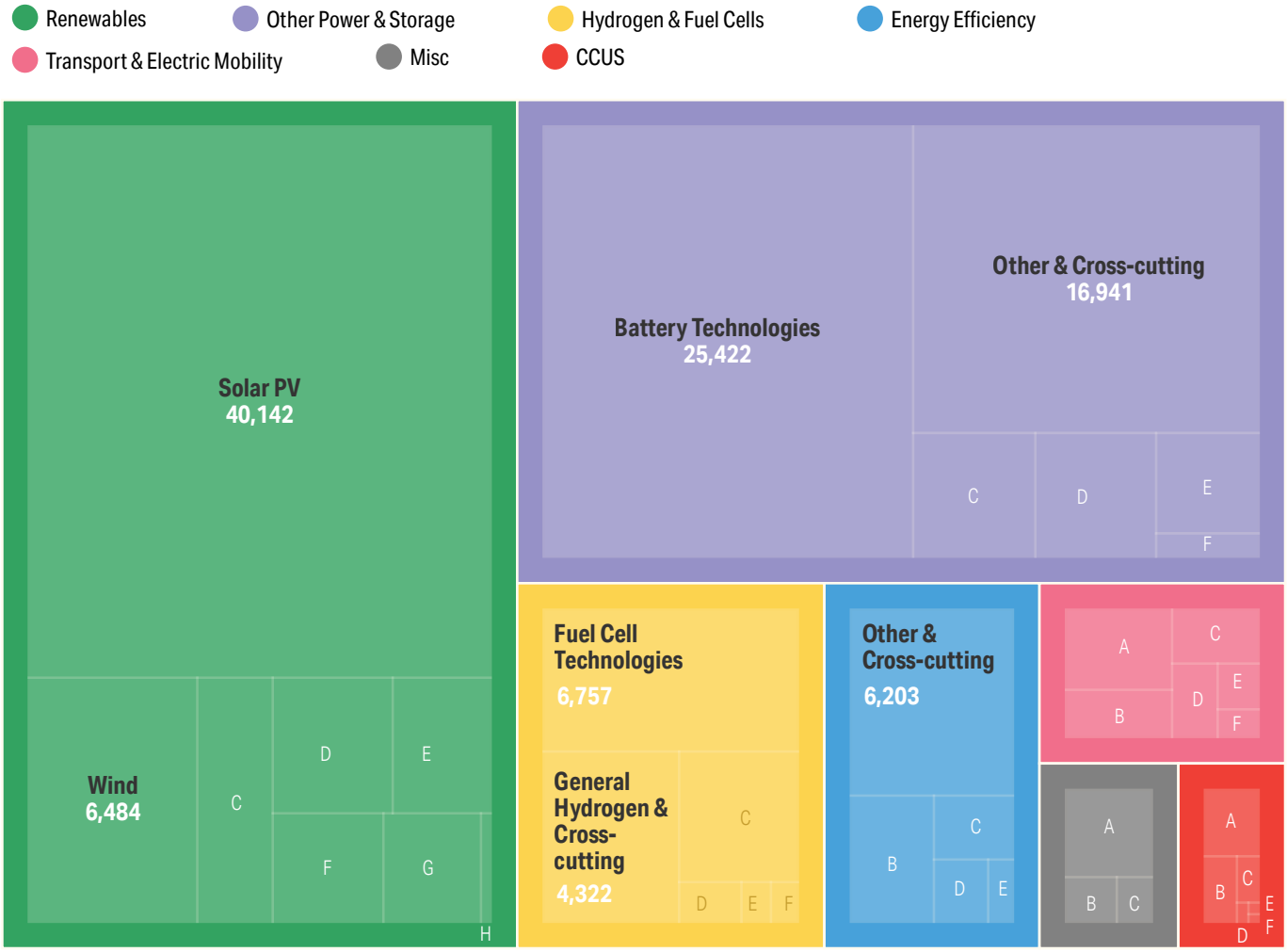
Who funds and who receives?

India's public clean energy RD&D system spans over a thousand projects, but investments gather around a handful of technologies

Budget data is available for approximately 85% of the portfolio and four agencies account for most declared funding. Figure 7 shows how funding is distributed across funding agencies and the institutions they support.

DST is the largest funder at roughly INR 401 crore (USD 42 million) across 705 projects – 52% of the portfolio by count – at a median project size of INR 36 lakh (USD 38,000). MNRE deploys INR 352 crore (USD 37 million) across just 39 projects, at a median of INR 3.46 crore (USD 362,000). CSIR follows at INR 170 crore (USD 18 million) through its centre-led model, and MeitY at INR 66 crore (USD 8 million), concentrated largely in batteries.

Fig. 6 Declared funding by technology category and subgroup



- C Bioenergy 2,905
- D Other & Cross-cutting 2,656
- E Hydropower 2,094
- F Hybrid & Integration 1,892
- G Solar Thermal & CSP 1,669
- H Ocean & Tidal 165

- C Supercapacitors & Energy Harvesting 2,418
- D Grid & Power Electronics 2,389
- E Energy Storage — General 1,646
- F Advanced Materials & Thermal Storage 381
- C Hydrogen Production — Electrolysis & Catalysis 2,907
- E Hydrogen Storage & Carriers 464
- D Hydrogen Production — Photocatalytic & Other 220
- F Catalysts & Advanced Materials 199

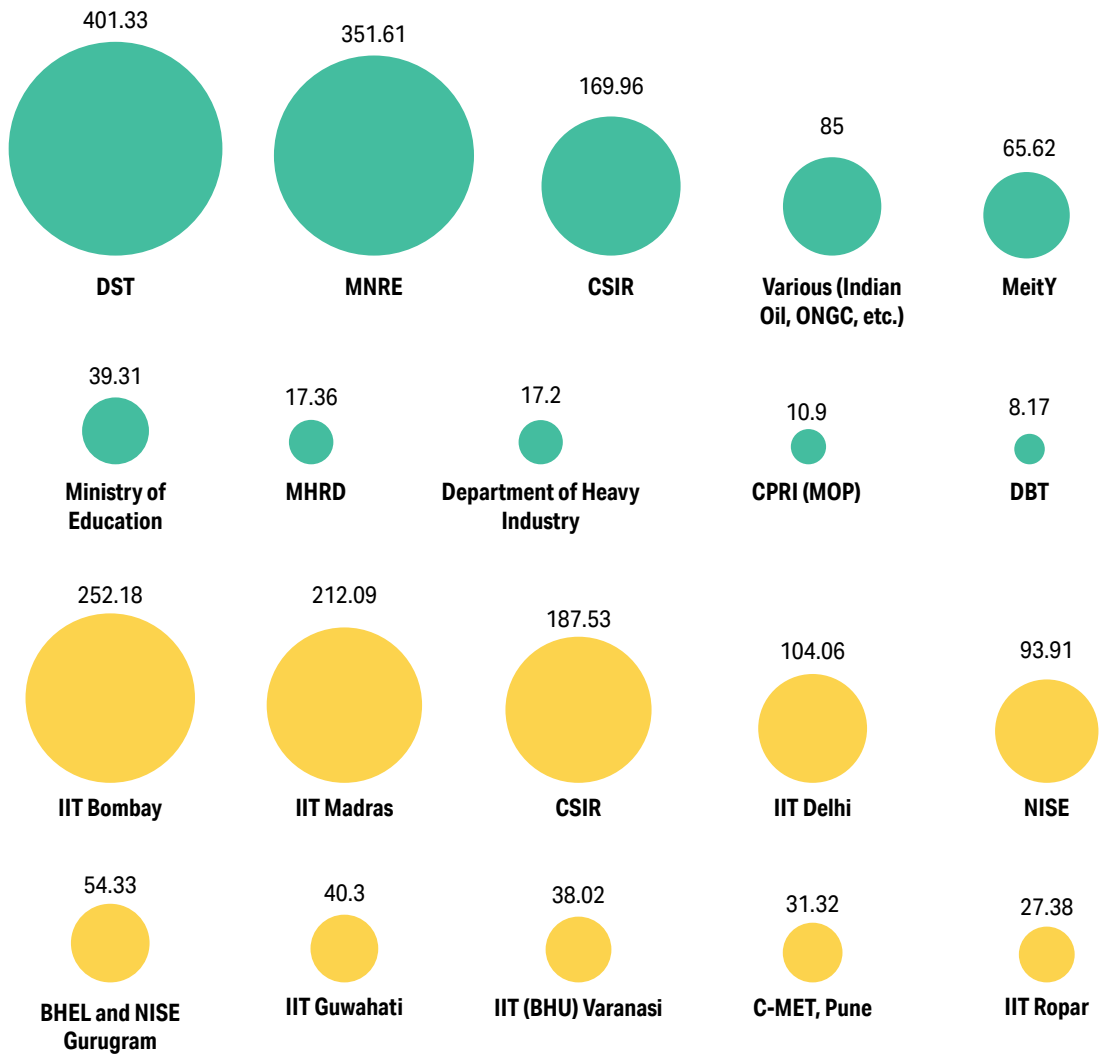
- B Industrial Processes & Combustion 2,157
- C Buildings & Cooling 1,040
- D Advanced Materials for Efficiency 695
- E Smart Grids & Energy Management 317
- A EV Charging & Grid Integration 2,037
- B Other (2W/3W, Lightweighting, Autonomous) 1,196
- C EV Drivetrains & Power Electronics 1,116

- D Hydrogen & Fuel Cell Vehicles 802
- E EV Battery & Thermal Management 449
- F Other & Cross-cutting 270
- A Cross-cutting & Other 2,251
- B Waste-to-energy and Thermal Recovery 683
- C Low Carbon Industry & Materials 470

- A CO_2 Utilisation—Fuels and Chemicals 1,318
- B Clean Coal & Cross-cutting 775
- C CO_2 Capture 371
- D Carbon Dioxide Removal 82
- E Geological Storage 44
- F CO_2 Utilisation—Materials 28

Source: Authors' analysis

Fig. 7 Declared funding by (a) funding agency and (b) recipient institution



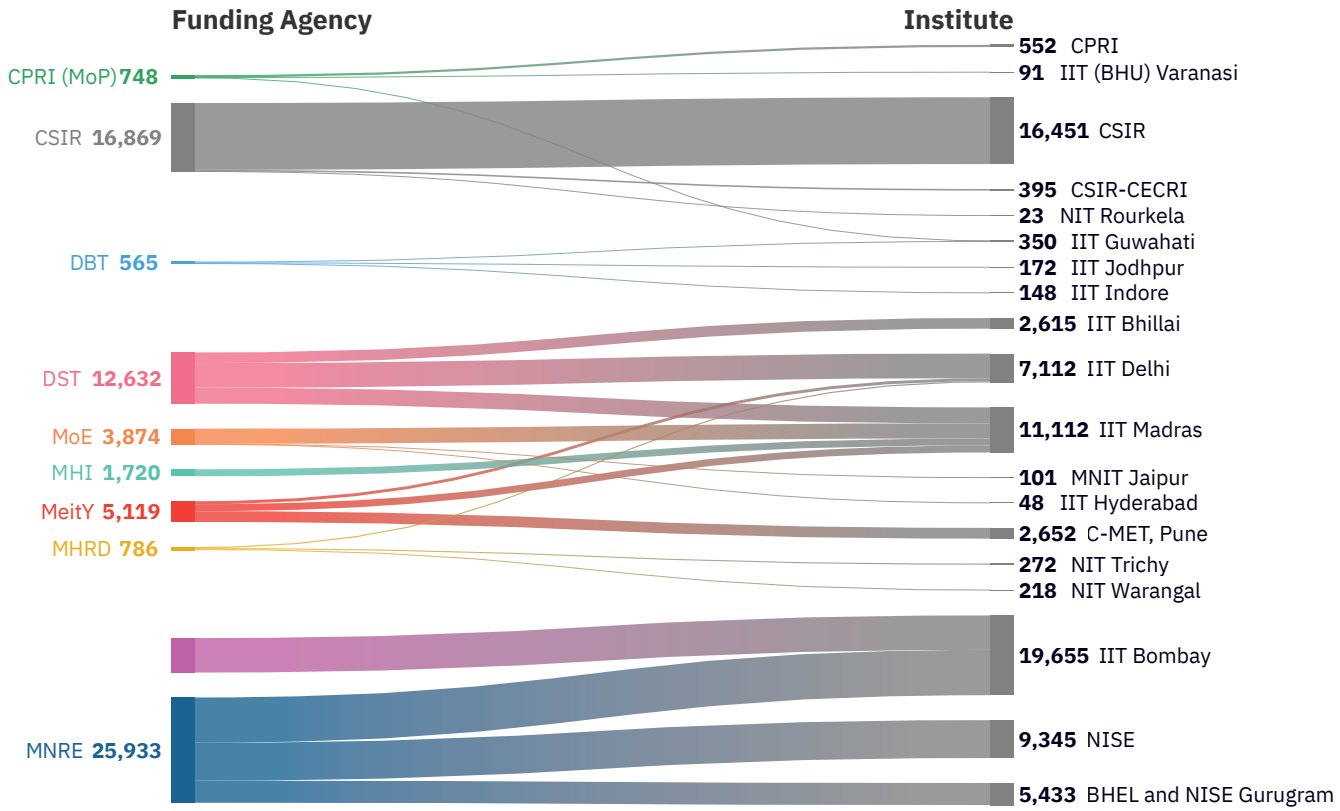
Source: Authors' analysis

The contrast between DST and MNRE is the clearest structural feature of the funding landscape. DST funds many small investigator-led grants across a wide institutional base. MNRE funds few large programmes directed at technologies closer to demonstration than to prototype. Their project titles differ accordingly: MNRE's tend to name specific performance targets – solar cells at a given efficiency, fuel cell stacks of a given power rating, measurement systems for offshore sites – while DST's more typically describe open-ended scientific investigation.

DST is the largest funder at roughly INR 401 crore (USD 42 million) across 705 projects – 52% of the portfolio by count.

Institutional concentration within the portfolio is also pronounced. The projects are distributed across India, but the top 10 institutions hold 47% of all projects and the top 20 hold 68%. Thirty-four institutions appear with only a single project, reflecting a long tail of occasional participation. This concentration is not inherently a weakness, as depth at anchor institutions can generate cumulative learning, but it does suggest that the

Fig. 8 Declared funding flows from the 10 largest public funding agencies to their three largest recipient institutions



Source: Authors' analysis

portfolio's breadth in terms of institution count is not matched by equivalent depth at most of those institutions.

Project sizes are mostly small and tightly clustered across technology categories, with 68% having declared budgets below INR 50 lakh (USD 52,000), the common scale of an individual faculty grant, sufficient for a small research group but rarely adequate for prototype development or pilot demonstration. Further, fewer than 180 projects have budgets exceeding INR 1 crore (USD 105,000) and less than 30 projects exceed INR 10 crore (USD 1 million). Median project size varies remarkably little across categories, ranging from INR 33 lakh (USD 35,000) in Transport to INR 39 lakh (USD 41,000) in both Other Power and Storage and Energy Efficiency. The uniformity is itself a finding, and Section 4 returns to it. To contextualise this against international norms: US DOE Energy Efficiency and Renewable Energy (EERE) applied research awards typically range from USD 1–5 million (INR 10–48 crore) per project, while EU Horizon project grants range from EUR 2–5 million (INR 22–55 crore[3]) (Department of Energy n.d.; European Commission 2024)[4].

What kind of innovation?

The study classifies every project along two dimensions. The first is degree of innovation: whether the work improves, adapts or optimises an existing technology (incremental) or pursues novel materials, architectures or fundamentally

3 INR 110 per EUR

4 These comparators should be read with care. The United States and the European Union fund research systems already operating at the technology frontier, so their grant sizes reflect a different stage of capability-building as well as substantially higher input costs, particularly researcher salaries.

new approaches (radical). The second is type of innovation: whether it targets the technology itself (product-oriented) or the means of producing it (process-oriented)[5].

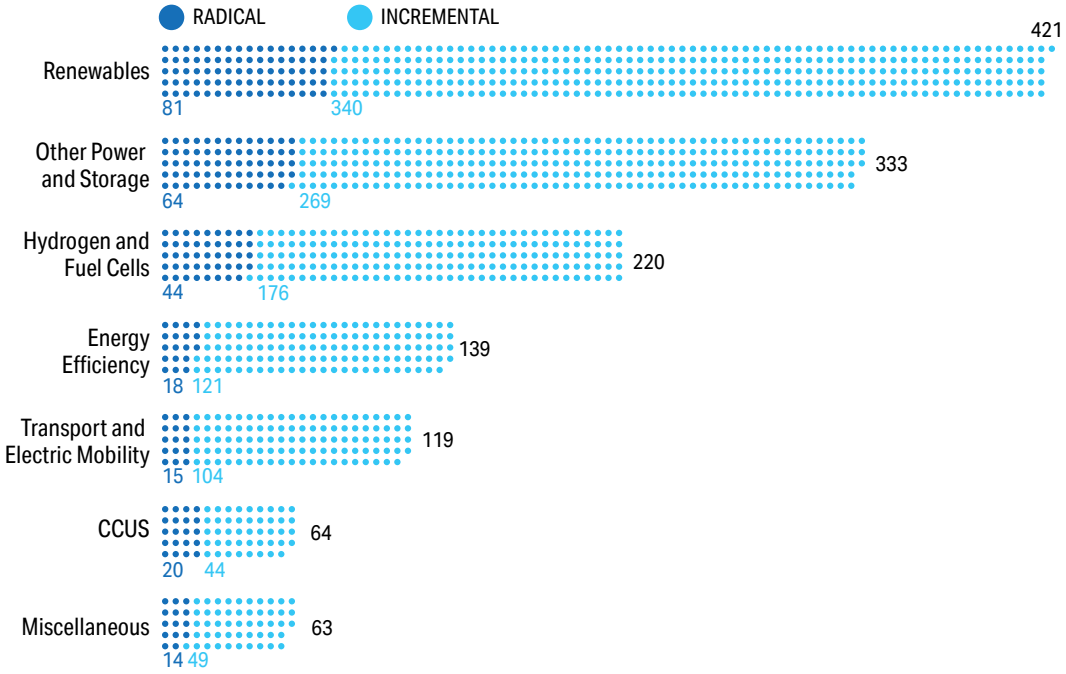
Approximately 81% of projects may be characterised as incremental, improving, adapting, or optimising existing technologies, and 19% as radical, involving novel materials, architectures, or fundamentally new approaches. Portfolio-wide, 67% of projects are product-oriented and 33% process-oriented. The figures below show how little this varies. Renewables, other power and storage, and hydrogen and fuel cells all sit within a few percentage points of the same incremental and product split. CCUS is the clear exception on both dimensions – the highest radical share at 31% and the only category weighted towards process work at 66% – and it is also the smallest category in the portfolio.

Weighting by budget rather than project count shifts the picture in most categories. In other power and storage, radical work accounts for 19% of projects but under 9% of budget. The same direction holds in hydrogen and fuel cells, where radical work takes 20% of projects and 15% of budget. Where this gap appears, larger grants are going predominantly to incremental work while exploratory research is funded in smaller units. This distinction matters for capability-building. Incremental funding deepens the ability to adapt and operate technologies already in deployment, which is the more immediately useful capability given India's scale of installation. Exploratory funding buys something different: the option to compete in technologies whose dominant design is not yet settled. Section 4 returns to this distinction and its implications.

International analysis of clean energy innovation systems suggests that countries at the technology frontier maintain parallel funding streams for early-stage and exploratory research alongside applied and demonstration funding, rather than concentrating resources in any one stage (Meckling et al. 2022; Zhang et al. 2021).

The sections that follow examine these patterns technology by technology.

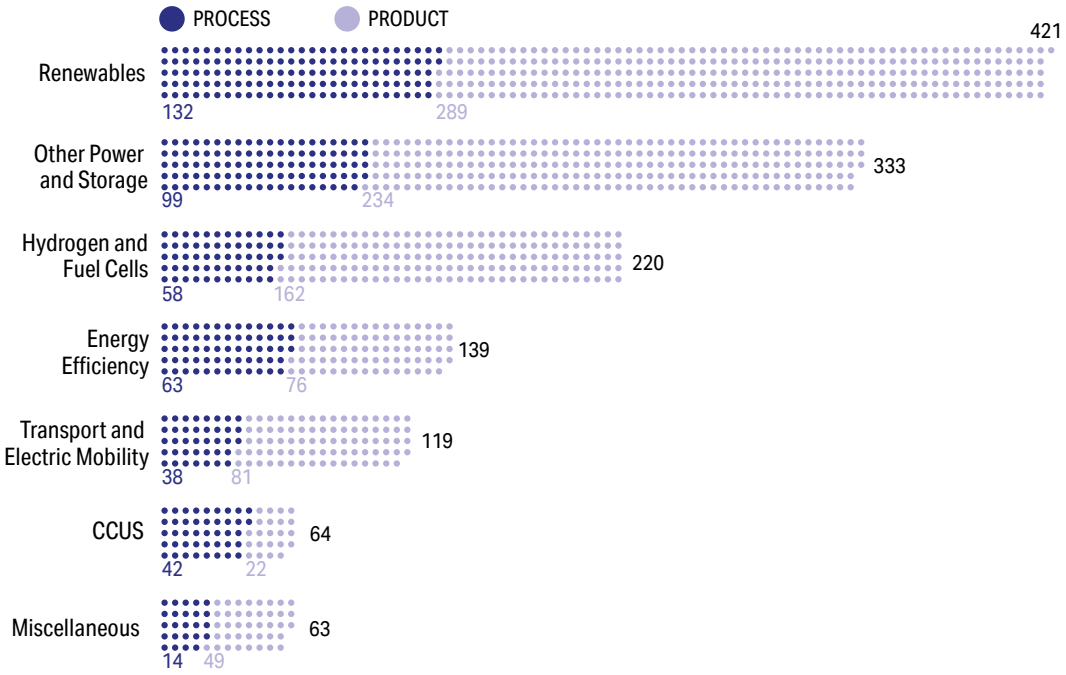
Fig. 9 Projects by degree of innovation and technology category



Source: Authors' analysis

5 The classification is applied at project level from stated objectives and descriptions, assigning each project its dominant character. Projects frequently contain elements of more than one type; the coding method and its limitations are set out in Section 2.

Fig. 10 Projects by type of innovation and technology category



Source: Authors' analysis

3.2 Renewable energy

Renewable energy technologies account for the single largest share of both project count and budget in the portfolio. The distribution within this category is highly uneven.

Solar photovoltaics dominate by a wide margin; wind, bioenergy, hydro, and ocean energy are present but receive substantially less research attention.

Solar

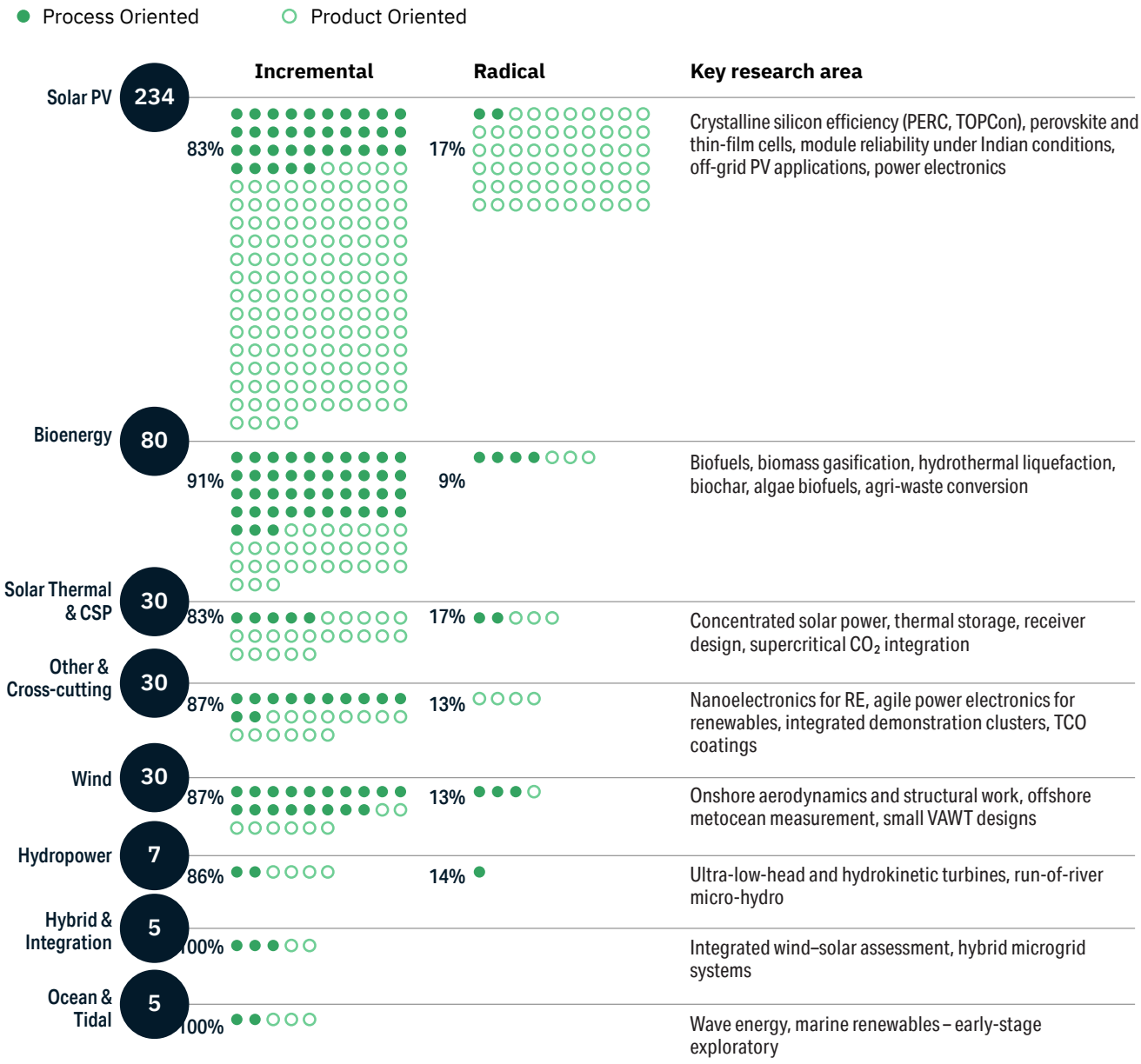
Solar occupies a central place in India's electricity transition, where even marginal improvements in module efficiency, reliability, and operational performance can translate into economically significant system-level gains. Indian operating conditions also present a distinct set of technical challenges. Intense irradiance, high ambient temperatures, dust, humidity, and seasonal variation affect performance and degradation in ways that may require context-specific adaptation (Sharma et al. 2013). Research on module durability, encapsulation materials, anti-reflective coatings, thermal management, and performance optimisation therefore has direct deployment relevance.

Most solar projects address crystalline silicon,[6] the technology underlying virtually all installed solar capacity globally (IEA 2026). A smaller set of projects focuses on next-generation photovoltaics, particularly perovskite and perovskite-silicon tandem cells.[7] These have attracted global research interest due to their potential to exceed silicon's efficiency ceiling, with a certified laboratory efficiency of 34.85% for a perovskite–silicon tandem cell reported in 2025 (LONGi 2025), although whether they can be made at a lower cost than silicon is not yet settled (pv magazine 2025). This cluster is comparatively well funded, driving the renewables radical budget share above its project share.

6 Crystalline silicon is the dominant commercial PV technology. PERC and TOPCon are successive cell architectures that improve efficiency by changing how the rear surface of the cell is constructed.

7 Perovskites are a family of crystalline materials that absorb light efficiently and can be deposited in thin layers. A tandem cell stacks a perovskite layer on silicon to capture more of the solar spectrum than either material alone.

Fig. 11 Renewables projects by subgroup, innovation profile and research focus



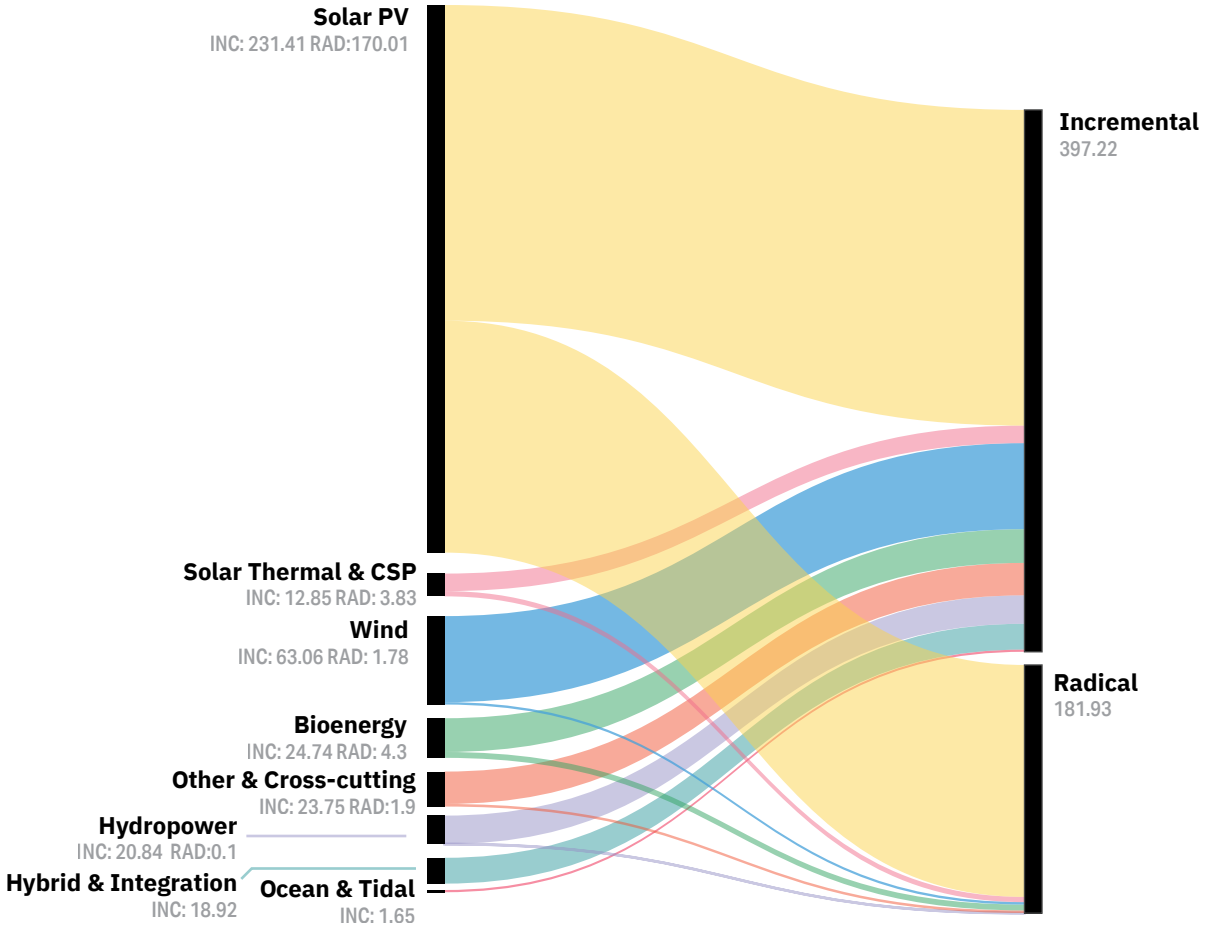
Source: Authors' analysis

A limited number of projects also address solar module end-of-life and recycling. With India's cumulative solar waste projected to reach about 340 kilotonnes by 2030 from existing capacity alone (about 600 kilotonnes including new capacity) and about 19,000 kilotonnes by 2050, research on material recovery, recycling processes, and module circularity is likely to become increasingly important (CEEW 2024). However, research activity in this area remains limited relative to that trajectory.

Wind energy

Wind RD&D addresses a different set of technical challenges: aerodynamic performance, structural integrity of blades and towers over 20–25 year operating lifetimes, accurate wind resource forecasting for grid integration, and the distinct engineering environment of offshore installations (Global Wind Energy Council 2024; IEA 2019). Unlike solar modules, turbines are large, site-specific civil and mechanical systems where RD&D gains require close coupling between research institutions and manufacturers or developers.

Fig. 12 Renewables budget flows by subgroup and degree of innovation



Source: Authors' analysis

The onshore wind research base in India is modest but relevant, addressing turbine blade structural optimisation, computational fluid dynamics for turbine flow modelling, and wind speed forecasting. These largely operate within established turbine architectures rather than exploring next-generation designs. Very few projects are relevant to offshore wind, the most substantial being an INR 44.6 crore (USD 4.7 million) MNRE project through NIWE on the Gulf of Khambhat and Gulf of Mannar – one of the largest projects in the renewables portfolio. Beyond resource assessment and site characterisation, the portfolio contains relatively little activity on the more advanced engineering challenges such as turbine-specific design for Indian Ocean conditions, corrosion management in tropical marine environments, cable systems, and operational and maintenance logistics in monsoon-affected seas. Globally, offshore wind research has concentrated on large turbine systems above 10–15 MW, floating foundation technologies for deep water, and transmission solutions for remote offshore sites (Global Wind Energy Council 2024). India's activity sits at the foundational end, and the pipeline beyond is modest.

3.3 Other power and storage

Power and storage technologies account for the second-largest share of both projects and budget. As renewable capacity expands, storage becomes central to balancing variable generation, maintaining grid reliability, and supporting power-system flexibility. India's storage requirement is expected to rise roughly five-fold between 2026–27 and 2031–32, from about 82 GWh to 411.4 GWh (CEA 2023).

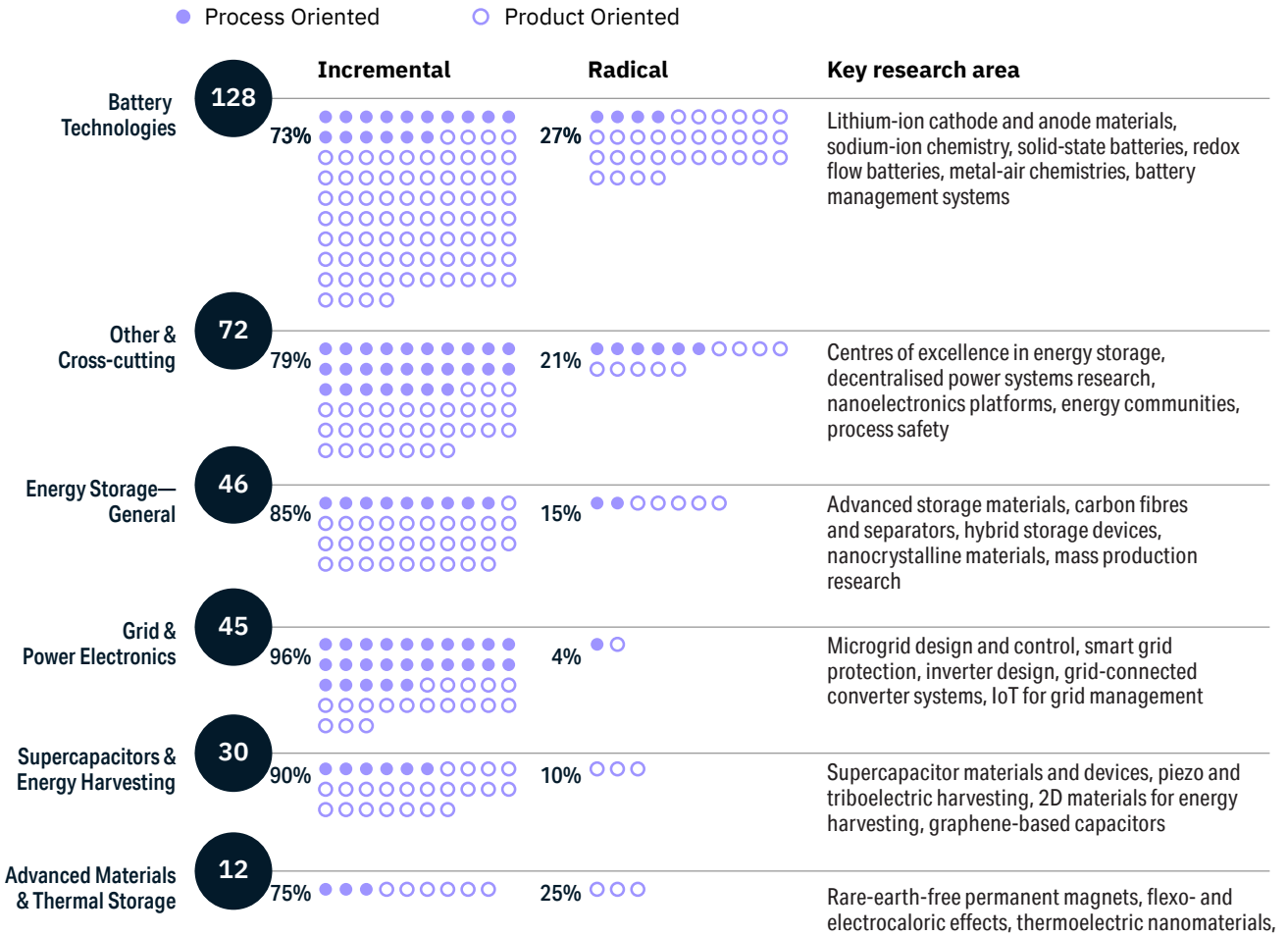
Unlike generation technologies, storage provides balancing and flexibility services across multiple time scales, from short-duration frequency regulation to longer-duration energy shifting and backup supply. The portfolio is heavily concentrated in electrochemical storage technologies, particularly lithium-ion batteries and associated battery management systems.

It is useful to set out where the global technology frontier sits. In 2025, average prices for turnkey battery storage systems fell to about USD 117/kWh, and average lithium-ion pack prices were 93% lower than in 2010 (BloombergNEF 2025a, 2025b). Batteries accounted for 40% of all energy patenting globally in 2023, an unprecedented share for a single technology area; China, South Korea, and Japan remain the leading sources of lithium-ion battery patents (IEA 2026). India enters this landscape at a stage when the dominant technology is relatively mature.

Lithium-ion research in the portfolio focuses on improving cycle life, thermal management, charging rates, and safety for Indian operating conditions. High ambient temperatures accelerate battery degr[8]adation, and dust and humidity create enclosure and thermal management challenges distinct from temperate climates. Research addressing these conditions is practically relevant to domestic deployment, even when it sits within mature global technology platforms (DST 2024).

A smaller but visible set of projects address alternative electrochemical chemistries, such as flow batteries, sodium-ion and metal-air (including zinc-air) batteries, where early research positioning

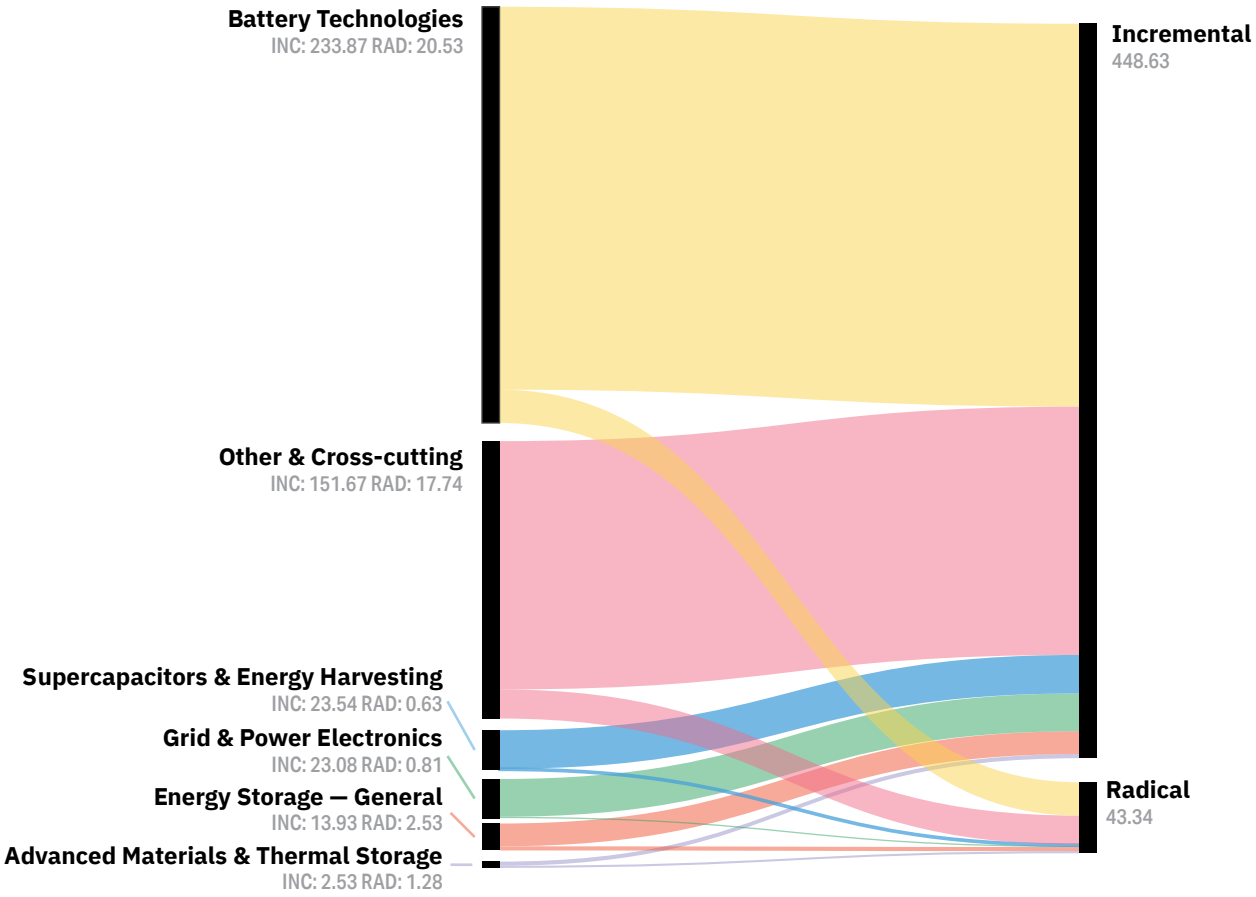
Fig. 13 Power and storage projects by subgroup, innovation profile, and research focus



Source: Authors' analysis

8 A flow battery stores energy in liquid electrolytes held in external tanks, so capacity is set by tank size rather than by the cell itself. Sodium-ion and metal-air chemistries substitute cheaper or more abundant materials for lithium, at some cost in energy density.

Fig. 14 Power and storage budget flows by subgroup and degree of innovation



Source: Authors' analysis

could matter. Flow batteries in particular scale energy capacity independently of power output, making them well suited to multi-hour or multi-day storage needs that lithium-ion storage serves less efficiently. Research across these chemistries is concentrated largely in materials synthesis, electrode design, electrolyte development, and laboratory-scale performance optimisation.

Beyond electrochemical storage, the portfolio covers grid technologies (including smart grids) and power electronics. These address the challenge of how storage assets interact with the grid, how power electronics manage charge and discharge, and how grid management systems optimise flexible assets.

As renewables penetration rises, longer-duration storage becomes increasingly important for system balancing. Yet, pumped hydro storage accounts for only a small number of projects despite accounting for about 175 GWh of the 411 GWh storage requirement that CEA projects for 2031–32 (CEA 2023). Compressed air energy storage, gravity-based systems, and other mechanical storage technologies are similarly limited.

This category has the lowest radical budget share in the portfolio: 19% of projects are radical, but under 9% of declared budget flows to them.

3.4 Hydrogen and fuel cells

The green hydrogen portfolio has grown meaningfully since 2019 as hydrogen gained prominence in India's policy discourse ahead of the National Green Hydrogen Mission launched in January 2023 (NITI Aayog and Rocky Mountain Institute 2022). The Mission carries an outlay of INR 19,744 crore (USD 2.1 billion) through 2029–30, aiming for approximately 5 million tonnes of green hydrogen

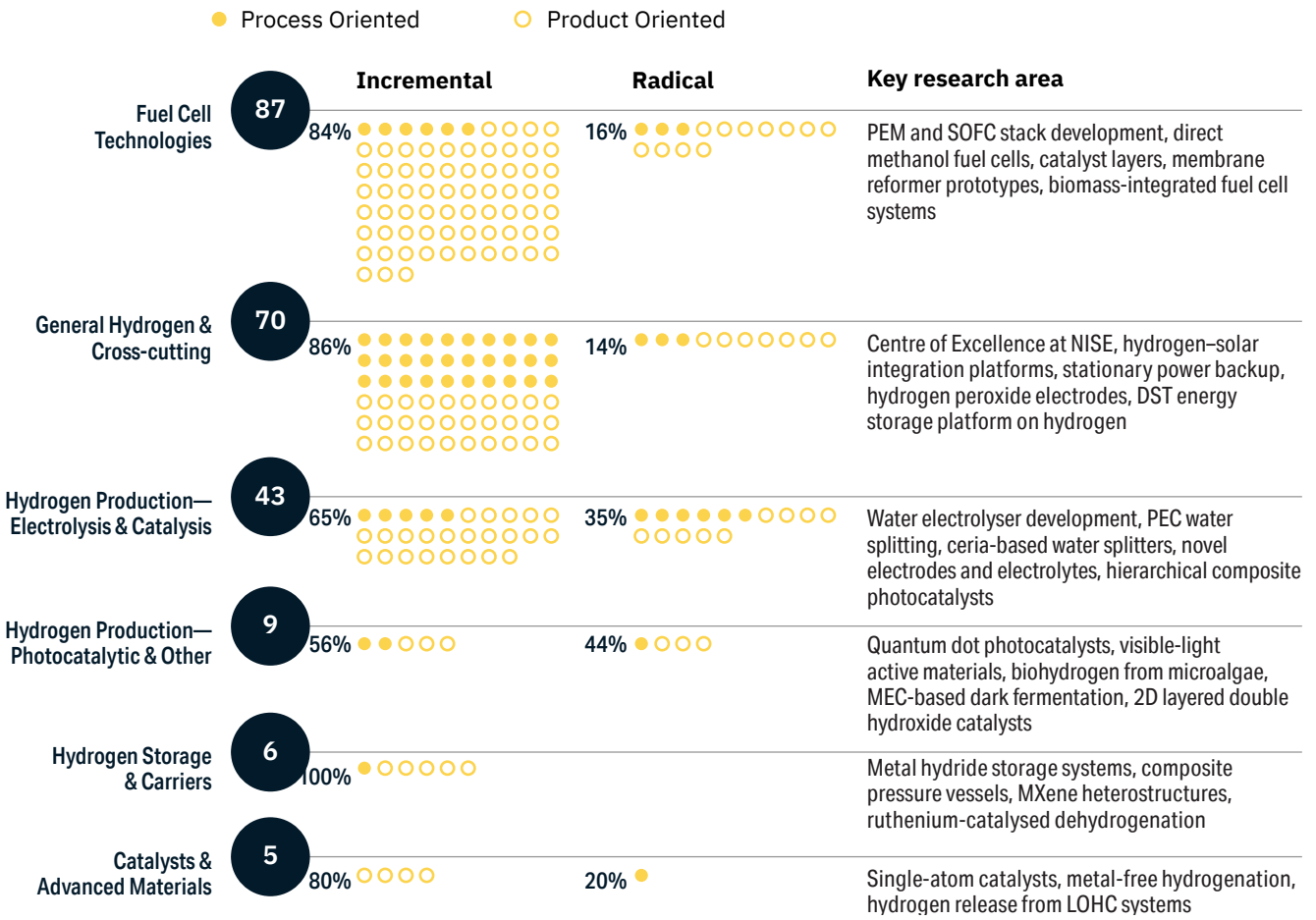
production capacity annually by 2030 and domestic electrolyser manufacturing capability with INR 400 crore (USD 42 million) earmarked for R&D activities (MNRE 2023).

Cost reduction remains a defining challenge in green hydrogen production. Hydrogen made by splitting water with renewable electricity remains substantially more expensive than hydrogen made from fossil fuels, and closing that gap depends on three things: better materials inside the electrolyser, better engineering of the complete system, and manufacturing at sufficient scale (International Renewable Energy Agency 2020; International Energy Agency 2024b).[9] India's Green Hydrogen Mission targets both production capacity and domestic manufacturing, so research would need to contribute across both of these.

Unlike solar or lithium-ion batteries, where dominant technology pathways are settled, green hydrogen technology pathways remain relatively unsettled at the global frontier. The portfolio's high incremental share should therefore be read against the research frontier rather than the maturity of the technology: most projects optimise known catalyst families, membranes and cell architectures rather than proposing new approaches.

The portfolio is concentrated in materials research. Most hydrogen projects work on catalysts, focusing particularly on replacing scarce platinum and

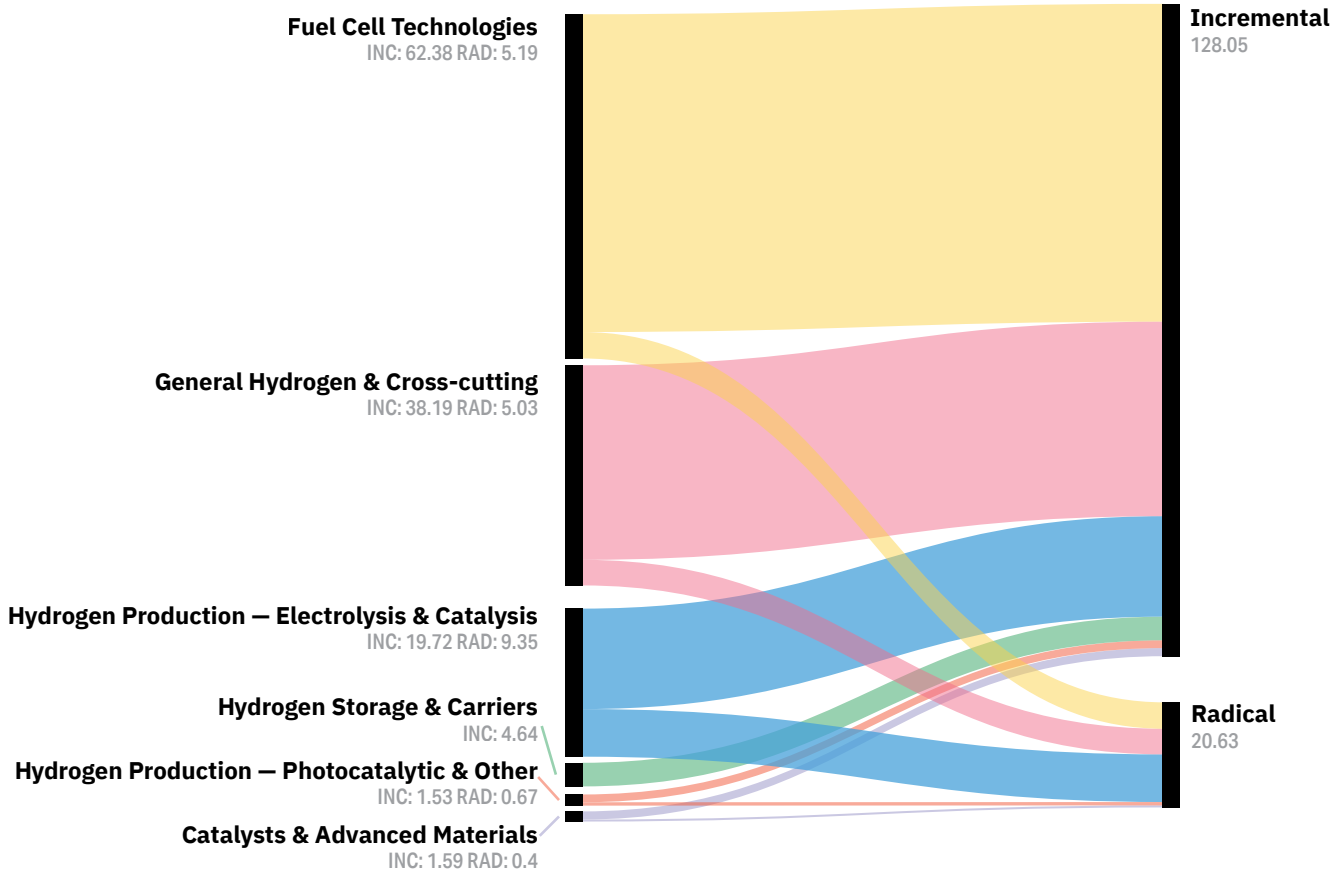
Fig. 15 Hydrogen and fuel cell projects by subgroup, innovation profile and research focus



Source: Authors' analysis

9 An electrolyser splits water into hydrogen and oxygen using electricity. The two commercially established designs, PEM and alkaline, differ in the membrane separating the two sides of the reaction. A "stack" is the assembly of individual cells that makes up a working unit.

Fig. 16 Hydrogen and fuel cell budget flows by subgroup and degree of innovation



Source: Authors' analysis.

iridium with cheaper, more abundant alternatives, or on improving the membranes and electrodes inside electrolysers.[10] This is a substantive strength: catalyst and membrane costs make up a large share of electrolyser cost, and matching platinum-group performance with cheaper materials remains unsolved globally. The most exploratory work in the category sits here too – novel nanostructures, MOF-derived catalysts, photoelectrochemical water splitting. These represent scientific exploration but sit several steps removed from the techno-economic challenges of industrial-scale hydrogen production (IRENA 2020; IEA 2024b).

What is largely absent is the next stage of the innovation chain: system-level electrolyser development, stack engineering, integration with variable renewable electricity, and pilot-scale demonstration. The largest hydrogen project in the portfolio develops a 20 kW low-temperature PEM fuel cell with high indigenous content (INR 21.4 crore, USD 2.2 million). The largest electrolysis project, CSIR's development of a water electrolyser for green hydrogen, is about half that size (INR 10.1 crore, USD 1.1 million); India's stated targets require electrolysers operating at gigawatt scale. Hydrogen storage and carrier technologies such as compressed hydrogen, liquid hydrogen, ammonia, and liquid organic hydrogen carriers, appear only in a handful of materials-level projects (Figure 15), with little system-level work despite being necessary for the export ambition the Mission states (IRENA 2022). Fuel cell research spans solid oxide, proton exchange membrane, and direct methanol

10 Catalysts accelerate the reaction without being consumed. Platinum-group metals perform well but are scarce and costly, which makes substitution a central research problem worldwide.

technologies across multiple institutions, with several projects developing indigenous membranes and catalyst layers to reduce dependence on imported Nafion. [11]

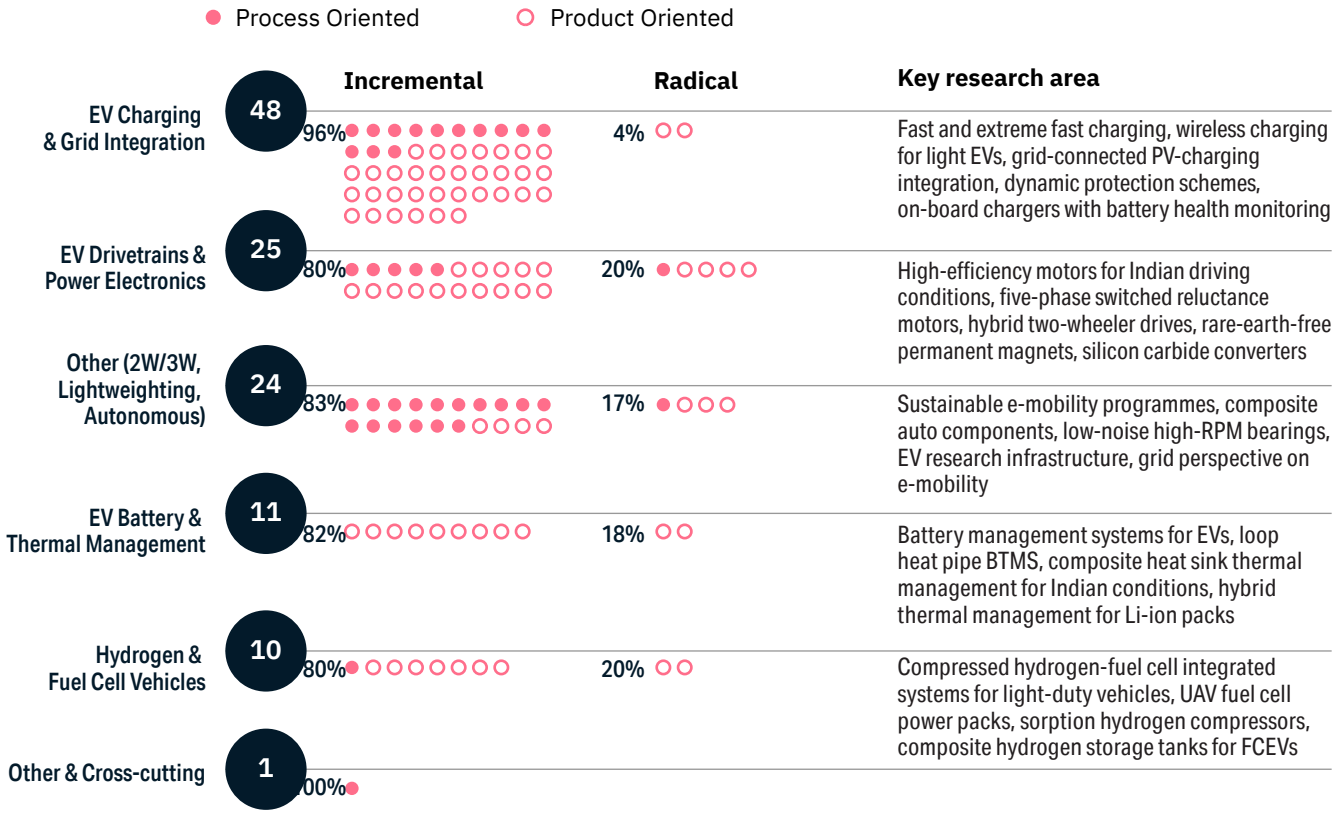
The demand context has also shifted with growth of AI infrastructure and data centres renewing interest in stationary hydrogen fuel cells as backup and primary power (IEA 2025a), a pathway that sits outside the transport and heavy industry framings these projects were designed around. Globally, fuel cell deployment has advanced most rapidly in Japan and South Korea through sustained government programmes and in China through subsidies for buses and trucks (IEA 2024b). India's deployment-linked support is more recent and smaller in scale with pilot projects for hydrogen buses, trucks, and refuelling stations under the National Green Hydrogen Mission, with an outlay of INR 496 crore to 2025–26, announced only in 2024 (MNRE 2024).Most projects in the portfolio predate this, and the research base is correspondingly exploratory and component-level.

3.5 Transport and electric mobility

India's transport sector sits at the intersection of two major policy objectives: accelerating vehicle electrification and building domestic manufacturing capabilities in strategic clean energy technologies. The FAME II scheme (2019–2024), the PM E-DRIVE scheme, and the ACC PLI scheme together constitute the core of India's policy framework for transport electrification and battery manufacturing (Ministry of Heavy Industries 2019; NITI Aayog and Rocky Mountain Institute 2019; NITI Aayog 2022; Ministry of Heavy Industries 2025).

Transport electrification poses a different research problem from generation technologies. The vehicle itself is largely a global product, and the

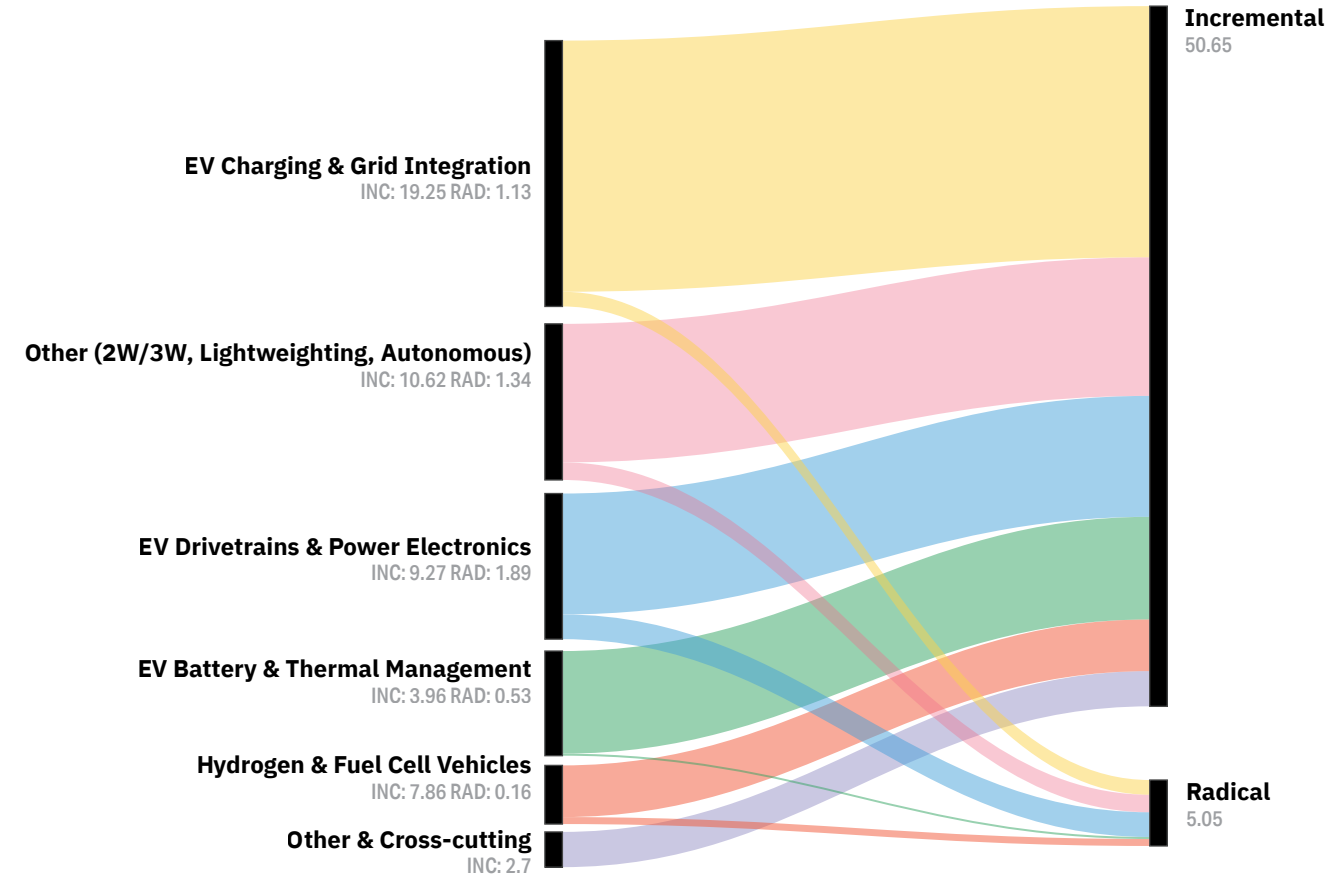
Fig. 17 Transport and e-mobility projects by subgroup, innovation profile and research focus



Source: Authors' analysis

11 Nafion is a proprietary membrane material with high chemical stability and correspondingly high cost, widely used in PEM systems.

Fig. 18 Transport and e-mobility budget flows by subgroup and degree of innovation



Source: Authors' analysis

components that matter – most cells,[12] motors, power electronics – are manufactured at scale internationally. Where India-specific research has the clearest value is in the operating environment: high ambient temperatures that accelerate battery degradation, cost constraints particular to two- and three-wheelers, and a grid that must absorb charging load alongside variable renewable generation.

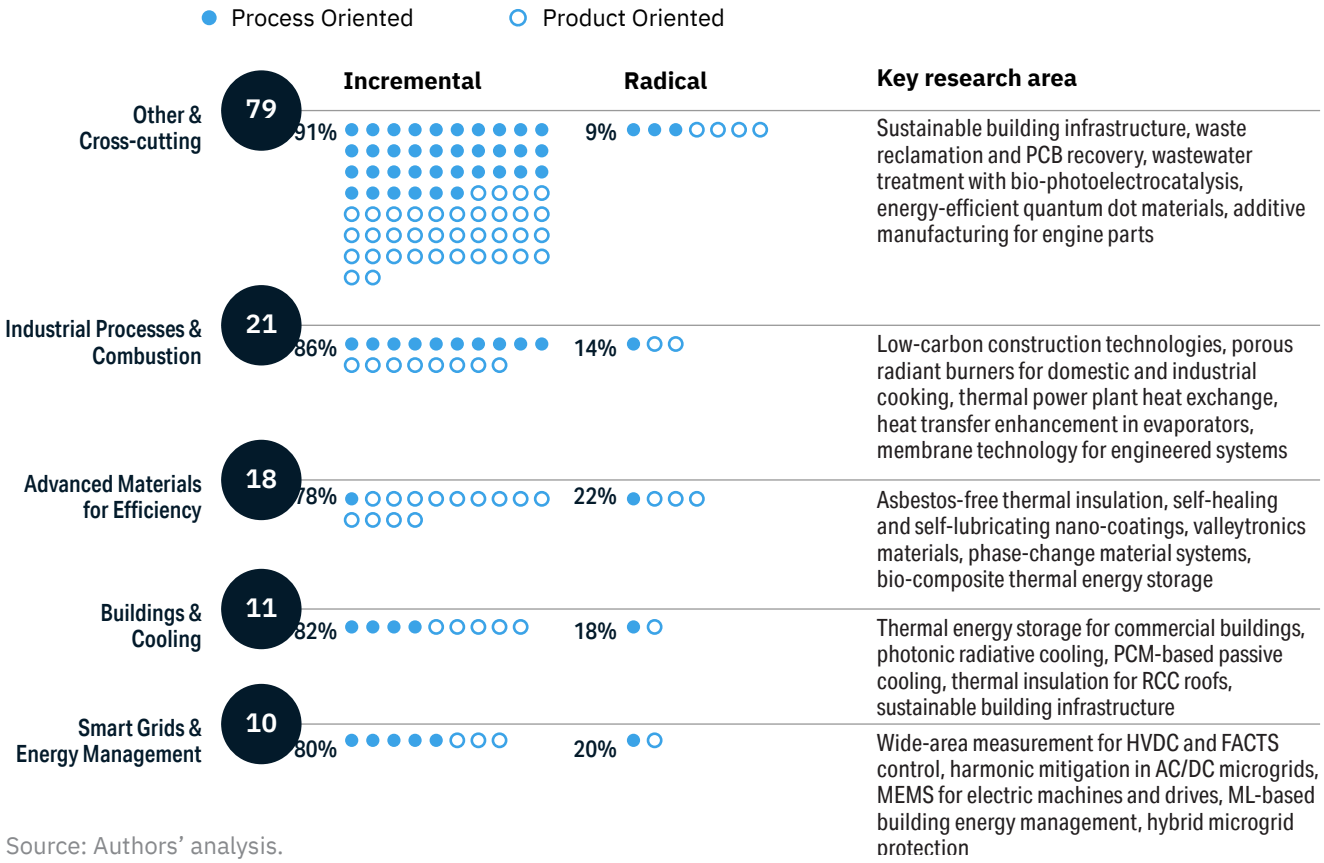
The portfolio reflects the third most clearly. Charging infrastructure and grid integration form the largest cluster, reflecting the ambition of India's EV targets. Drivetrain and power electronics research follows, including work on rare-earth-free permanent magnets and silicon carbide converters, both of which bear on import dependence in the motor and inverter supply chain. [13]

Less than 24 projects focus explicitly on two- and three-wheeler EVs, a number that almost certainly undercounts the true research activity directed at this segment, as many relevant projects within the drivetrain and charging clusters address 2W/3W applications without stating this explicitly in their titles. This segment accounts for over 90% of India's EV sales (IESA 2026) and presents engineering challenges – thermal management in high-ambient-temperature conditions, aggressive duty cycles, cost-per-kilometre constraints – that research originating in other contexts may not

12 It should be noted that the transport portfolio captures only battery projects whose titles explicitly identify an electric mobility or vehicle application. A much larger body of battery RD&D, including research on cell chemistries, electrode materials, electrolytes, and battery materials, is classified under Other Power and Storage to maintain a technology-based classification. While some of these projects are likely intended for electric vehicle applications, this is not always evident from publicly available titles or descriptions.

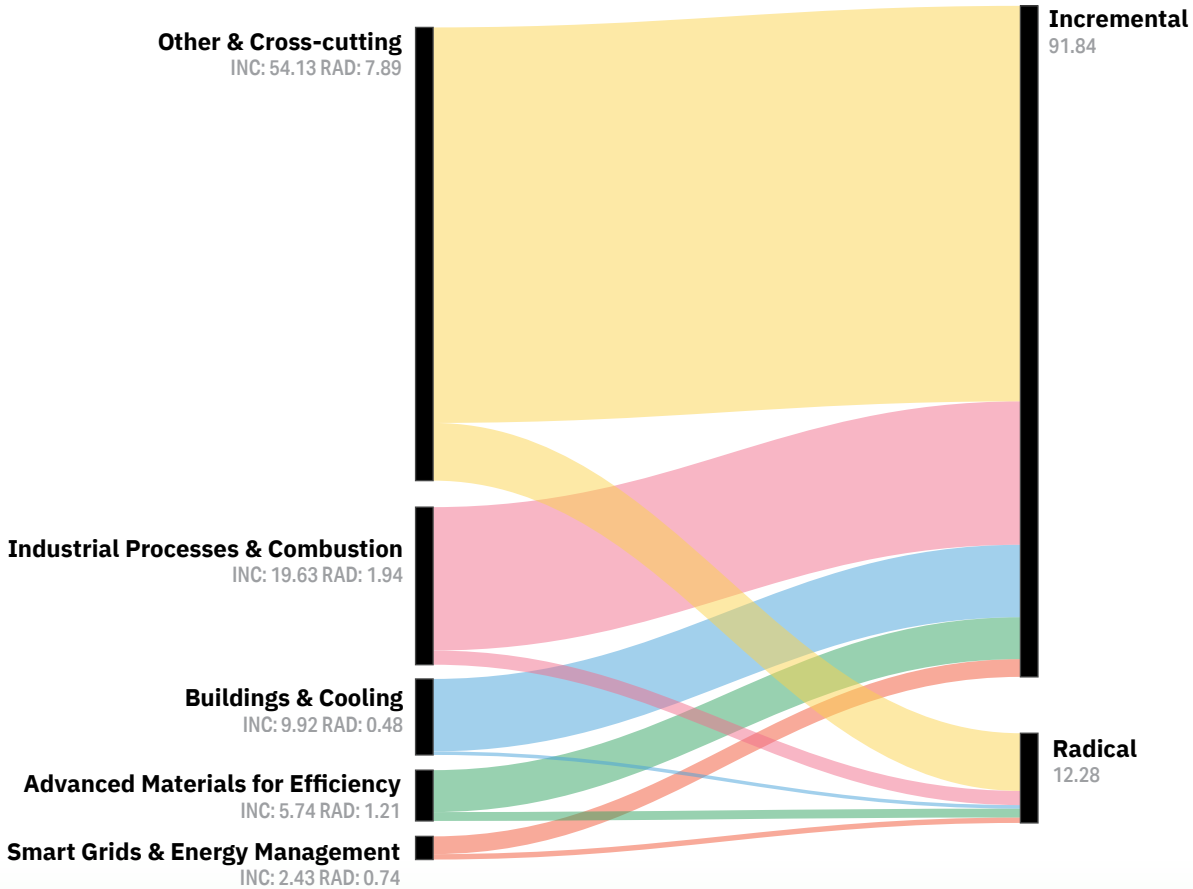
13 Permanent magnet motors are the standard choice for EV drivetrains but depend on rare-earth elements concentrated in a few countries. Silicon carbide is a semiconductor material that handles higher voltages and temperatures more efficiently than conventional silicon in power converters.

Fig. 19 Energy efficiency projects by subgroup, innovation profile and research focus



Source: Authors' analysis.

Fig. 20 Energy efficiency budget flows by subgroup and degree of innovation



Source: Authors' analysis

address (IEA 2024a; DST 2024). It is the segment where India-specific research has the strongest claim to comparative advantage, and the visible portfolio does not obviously reflect that.

Hydrogen and fuel cell vehicle systems are a small but important cluster representing public research effort towards hydrogen-powered mobility. Battery and thermal management for vehicles appears in 11 projects, notably thinner than the battery research documented in Section 3.3, where cell-level work dominates. The distinction matters because cell chemistry and pack-level thermal management for Indian road and climate conditions are different problems, and the portfolio is weighted towards the former.

3.6 Energy efficiency

Unlike solar or battery technologies, where research concentrates around a defined set of materials and systems, efficiency improvements span a wide range of sectors (such as transport, buildings, and industry), technologies, and scales. The result is a portfolio that is wide in topical coverage but thin in depth across most of its constituent areas.

Industrial and thermal efficiency accounts for a small set of projects, a modest base given that the industrial sector is India's largest energy-consuming sector (over 50% of total final energy consumption in 2023–24; MoSPI 2026). The work is mostly incremental, focusing on MSME combustion systems, process optimisation in manufacturing, and improvements in thermal equipment.

Buildings and cooling are similarly modest in scale. These span passive cooling systems, thermal insulation materials, phase change materials for thermal storage, and one Mission Innovation-linked resource centre on affordable heating and cooling.[14] These areas are highly relevant to India's climate conditions and rapidly growing cooling demand (MoEFCC 2019), yet the level of research activity is limited relative to the scale of future energy demand growth in the buildings sector. Phase change materials absorb and release heat as they melt and solidify, allowing a building to store coolness generated at night for use during the day.

A third cluster comprises cross-cutting systems and digital efficiency, including smart grids, energy management systems, and IoT-enabled optimisation. These projects reflect emerging directions in global energy systems, where digitalisation plays an increasing role in efficiency gains. A fourth addresses materials and component-level efficiency improvements, including advanced thermal materials, coatings, thermoelectric systems, and electronic components.

Energy efficiency is the second-most process-oriented category in the portfolio after CCUS, at 45% process work. This is intrinsic to the field, where the research question is usually about how something is done rather than what is built.

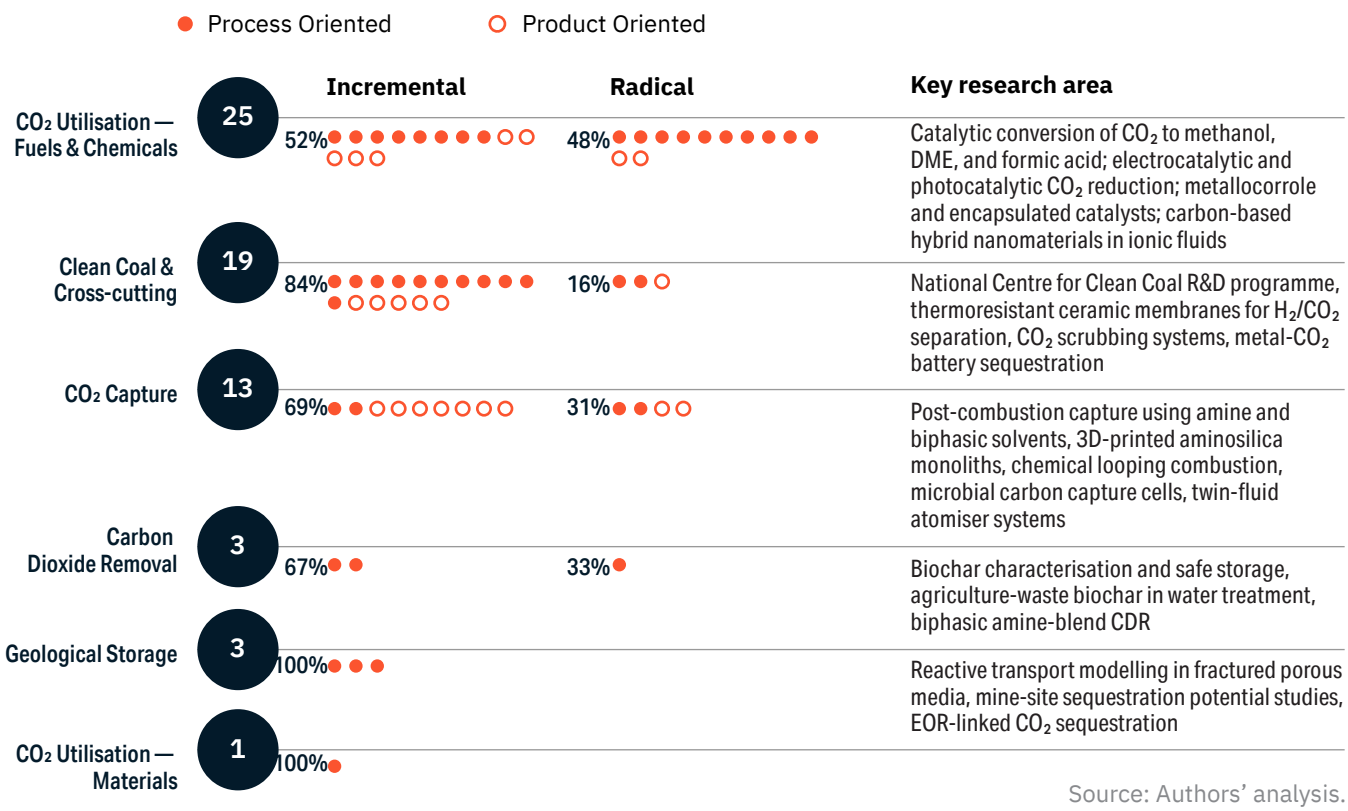
3.7 Carbon capture, utilisation and storage

CCUS is the smallest category in the portfolio. However, the data covers activities only up to 2024, and India's CCUS policy landscape has changed substantially since then. DST launched India's first CCUS R&D Roadmap in December 2025, targeting power and hard-to-abate sectors such as cement and steel (DST 2025a). Following this, the Union Budget 2026–27 allocated INR 20,000 crore (USD 2.1 billion) over five years to scale up CCUS technologies (Ministry of Finance 2026). The research portfolio documented here must therefore be read as a baseline of where India's CCUS research capacity stood on the eve of this policy expansion, not a reflection of where it is heading.

CCUS globally carries a contested track record with mixed views on its role in decarbonisation. High investment and operating costs, and inflation-sensitive components make CCUS economically challenging compared with alternative technologies

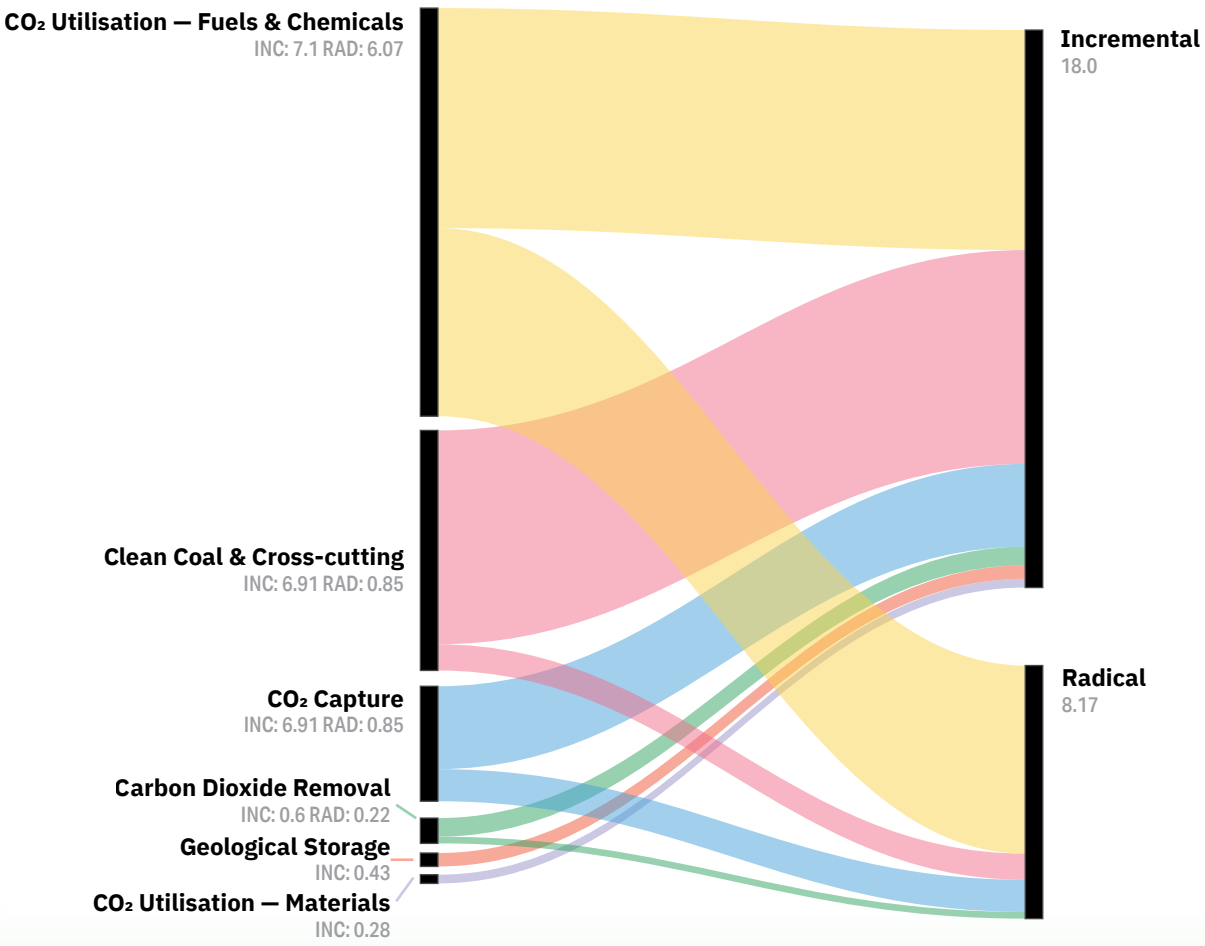
14 Phase change materials absorb and release heat as they melt and solidify, allowing a building to store coolness generated at night for use during the day.

Fig. 21 CCUS projects by subgroup, innovation profile and research focus



Source: Authors' analysis.

Fig. 22 CCUS budget flows by subgroup and degree of innovation



Source: Authors' analysis

CCUS portfolio has the highest radical project share of any technology category at 31%.

(IEEFA 2022). For India's steel sector specifically, some analysts have questioned whether CCUS is the most efficient decarbonisation pathway, particularly given the emergence of green hydrogen-based direct reduced iron routes and the energy security implications of continued metallurgical coal dependence (Nicholas 2026). These are live debates, and the appropriate RD&D posture needs to account for them.

Despite its small overall size, the CCUS portfolio has the highest radical project share of any technology category at 31%, consistent whether measured by project count or budget. This could be because CCUS lacks a settled dominant technology pathway globally (IEA 2020). Unlike solar PV or lithium-ion batteries, capture, utilisation, and storage span multiple competing approaches at varying readiness levels, which creates space for exploratory research without requiring researchers to justify departing from an established baseline.

The largest cluster is carbon utilisation, converting captured CO_2 into chemicals, fuels, or materials. Storage is largely missing from the portfolio. That said, NTPC, in collaboration with IIT Bombay, completed drilling India's first dedicated CO_2 storage test well at Pakri Barwadih in Jharkhand in November 2025 and began a second well for injection and monitoring in December 2025 (IANS 2025). The DST CCUS Roadmap has identified priority industrial and geological clusters by mapping basins, including the Krishna-Godavari Basin, Rajasthan's geological formations, and Tamil Nadu's sedimentary zones, linking them with high-emission industrial sectors to enable shared CO_2 transport and storage infrastructure (DST 2025a). The gap between these strategic mapping exercises and the research base that would need to support them is currently wide.

DST has established five Carbon Capture and Utilisation testbeds in the cement sector as a first-of-its-kind academia-industry research and innovation cluster, focusing on developing innovative catalysts, materials, electrolyser technology, and reactors to reduce the cost of green cement via CCU routes (DST 2025b). This initiative postdates the portfolio data and represents a sector-specific, demonstration-linked research model that has been largely absent from the portfolio so far.

The portfolio also includes some projects under carbon dioxide removal (CDR), including biochar and algae-based carbon sequestration approaches. These sit at the more speculative end of the carbon management spectrum but reflect growing global interest in biological and hybrid removal pathways.

4 Interpreting the Portfolio

Section 3 describes what the portfolio contains. This section asks what it amounts to: which strategic objectives the observed mix of research activity is capable of serving, where the portfolio sits relative to India's stated industrial ambitions, and what features of the funding system account for the pattern. It proceeds from a classification of research activity by objective, through the deployment orientation and the manufacturing question that follow from it, to the structure of the funding system itself.

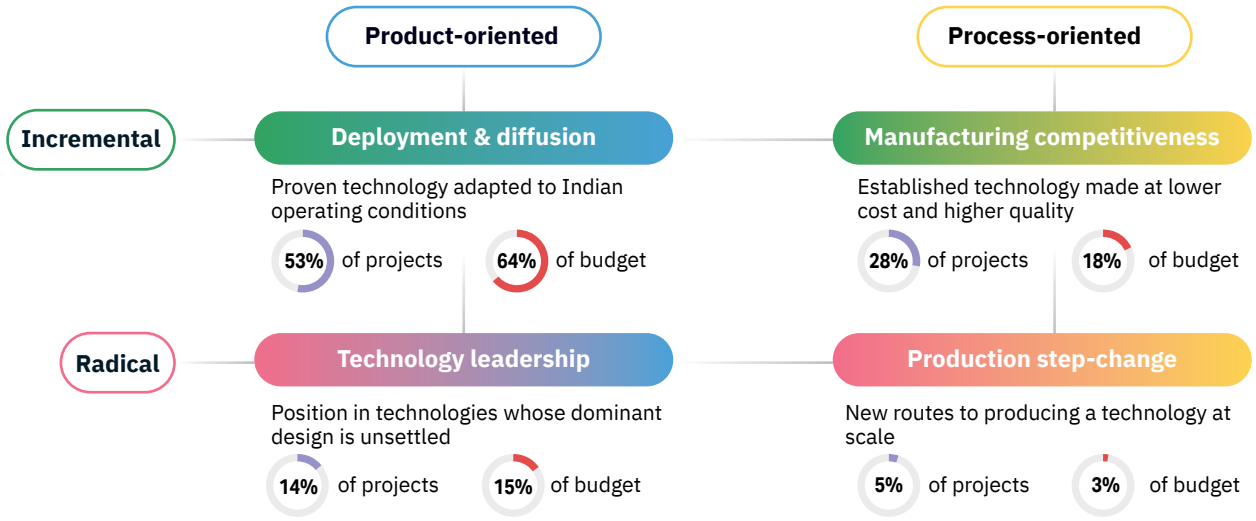
4.1 Research activity and strategic objective

Each choice of degree and type of innovation may reflect a different strategic objective, which Figure 23 sets out as a 2x2 matrix.

The quadrants describe the objective that each type and degree of research is most closely associated with, rather than the only purpose it can serve. Individual projects often contribute to multiple overlapping objectives, and countries pursuing manufacturing competitiveness will also require deployment research and radical innovation, while those pursuing technology leadership will need a strong production base. The matrix may therefore be read as a way of examining where the centre of gravity of the portfolio lies, rather than as a prescriptive classification.

Viewed through this lens, India's public RD&D portfolio, as captured in the sample, is heavily weighted towards supporting deployment and diffusion. That weighting sits uneasily with India's green industrial policy ambitions, which increasingly emphasise domestic manufacturing. Measured against manufacturing competitiveness or technology leadership, the distribution appears misaligned, and 15% of the budget is a modest position in technologies where design competition remains open. Where the policy record points to pursuing several objectives at once, the mapped portfolio does not show the differentiated instruments each would require.

Fig. 23 Where public RD&D effort sits: projects and budget by strategic objective



Source: Authors' classification and analysis

India's public RD&D portfolio, as captured in the sample, is heavily weighted towards supporting deployment and diffusion.

The value of this matrix lies in making the balance and trade-offs between these objectives visible. At present, the composition of India's public RD&D portfolio appears to reflect the cumulative outcome of many independent funding decisions, but this review found little indication in the public record that the overall balance is being considered strategically. As public resources become increasingly constrained and clean energy technologies continue to diversify, the question is likely to become less whether more RD&D is needed, and increasingly what capabilities limited RD&D resources should prioritise.

This suggests two potential priorities for strengthening RD&D governance. First, RD&D strategies should articulate capability objectives alongside technology priorities, making explicit the role public investment is expected to play in supporting deployment, manufacturing competitiveness, and technology leadership. Second, portfolio-level monitoring should complement project-level evaluation, allowing governments to assess whether aggregate investment remains aligned with evolving national objectives. Viewed in this way, the matrix is not simply a way of classifying research projects. It is a tool for thinking about how public RD&D contributes to broader industrial strategy.

A deployment-oriented innovation system

The clearest pattern emerging from the portfolio is not which technologies India researches, but the type of knowledge the system appears structured to produce. Across the database, roughly 81% of projects may be classified as incremental innovations that improve technologies already dominant in global commercial deployment – including crystalline silicon photovoltaics, lithium-ion batteries, electric mobility systems, and conventional electrolysers – or adapt them to Indian operating conditions.

This emphasis reflects India's development context. India's transition is occurring under conditions different from those of countries that have already built clean energy capabilities, characterised by rapidly growing energy demand, constrained public RD&D budgets, high technology import dependence, and the need to deploy at very large scale in cost-sensitive markets. Climatic conditions, grid characteristics, industrial structure, and cost constraints also create important adaptation requirements that imported technologies may not automatically address.

Under these conditions, adaptation-oriented research can generate real value by improving battery thermal management for high ambient temperatures, reducing solar module degradation under dust and humidity, or developing low-cost charging systems, and may yield larger near-term economic and deployment benefits than highly speculative frontier research (Lall 1992; Bell and Figueiredo 2012). The predominance of incremental, product-oriented innovation need not indicate a weak research system; it can be read as a reasonable response to the demands of deployment.

Research effort and manufacturing ambition

The question, however, is whether this emphasis remains sufficient as India's objectives evolve. One way to read this is as a question of sequencing. A deployment-weighted portfolio has been broadly fit for purpose while the priority was installing capacity rapidly, but it will need to shift as manufacturing becomes a stated objective, and that shift is more likely to be orderly if there is a framework for deciding the intended balance and revisiting it periodically. Over the past decade, industrial policy has increasingly shifted beyond deployment towards building domestic manufacturing capability through initiatives such as the PLI schemes for solar photovoltaics and advanced chemistry cells as well as the National Green Hydrogen Mission.

At the level of technology choice, the RD&D portfolio appears broadly aligned with these priorities. Solar PV, batteries, hydrogen, and electric mobility collectively account for a large share of project

activity; however, this broad alignment should not be taken as evidence that the portfolio is necessarily well-balanced. The more important question is what capabilities that research is intended to develop.

This is not the first time India's public energy RD&D has been out of step with wider policy priorities: Zhang et al. (2021) find that energy RD&D by state-owned enterprises in India and other major emerging economies remained weighted towards fossil fuels and nuclear power even as renewables scaled. Here the database points to a tension that runs across most technology areas. India's flagship industrial programmes are all fundamentally concerned with building competitive manufacturing capability, yet the research portfolio remains weighted towards product innovation rather than the process innovation needed to manufacture those products efficiently at scale. Process-oriented research accounts for around one-third of projects but only one-fifth of declared expenditure, and the divergence is greatest precisely where manufacturing capability has become an explicit policy objective. In power and storage, which includes battery research relevant to the ACC PLI scheme, 84% of declared expenditure is concentrated in incremental product innovation. In renewables, 54% of funding supports incremental product innovation and a further 26% supports radical product innovation, leaving only 20% for process-oriented research combined. This is particularly noteworthy because India's principal challenge in sectors such as solar is increasingly one of manufacturing at competitive cost rather than improving the performance of commercially mature technologies (Gulia et al. 2023; Sharma et al. 2025). CCUS is the only technology category where process innovation receives greater emphasis, although it remains the smallest portfolio overall.

India's industrial ambitions demand manufacturing capability, but its RD&D portfolio remains weighted towards product rather than process innovation.

This is not an argument against product innovation. Product innovation contributes to manufacturing competitiveness as better product designs can reduce costs and enable simpler production. The question is whether it is being complemented by sufficient investment in process innovation, which in mature manufacturing economies has been central to improving production efficiency, reducing costs, and supporting industrial learning (Utterback and Abernathy 1975; Pisano and Shih 2012; Nahm and Steinfeld 2014).

China's experience in solar PV illustrates why the distinction matters. A global study of solar module costs finds that, as the technology matured after 2001, cost reductions came increasingly from manufacturing, through larger factories and better production processes, and not only from improvements to the cells themselves (Kavlak, McNerney, and Trancik 2018). China's rise in the industry rested heavily on this kind of manufacturing scale-up and process innovation, and by 2021, China was home to the world's ten largest suppliers of PV manufacturing equipment (Huang et al. 2016; Nahm and Steinfeld 2014; IEA 2022). Over time, these manufacturing capabilities also became a source of innovation in their own right: Chinese firms developed R&D strengths in commercialising new technologies and scaling them rapidly to mass production (Nahm and Steinfeld 2014; Nahm 2021). While the conditions under which its PV industry grew are not reproducible, the case suggests process innovation can support not only manufacturing competitiveness but also future technology leadership.

If strengthening domestic manufacturing capability is among the objectives of India's public RD&D system, these findings suggest a need to reconsider whether the current approach to supporting research is fully aligned with that objective. Much of the activity represented in the process-oriented quadrants sits closer to industrial production than conventional laboratory research. Supporting

these capabilities may therefore require different forms of collaboration between public research institutions and industry, and a more explicit recognition of process innovation as a strategic objective in its own right.

4.2 A fragmented, investigator-led funding system

The patterns described in the previous sections are unlikely to be explained by technology choice alone. They also likely reflect the structure of India's public RD&D funding system.

The database suggests a broad research base with projects spread across a large number of IITs, NITs, CSIR laboratories, and specialised centres, funded by multiple ministries and agencies. This diversity is an important strength, allowing expertise to develop across a wide institutional base. At the same time, it creates a governance challenge. A Mission Innovation country review of India's hydrogen RD&D notes that hydrogen funding alone 'sits across several departments with respect to their sector mandate', spanning MNRE, DST, CSIR, MoPNG, DRDO, and DSIR, each running independent programmes (Delaval et al. 2022). The database confirms this institutional fragmentation. Fragmentation is not a weakness in itself, and some coordination may be occurring through technology missions, inter-ministerial committees, or informal alignment between agencies that is not visible in project data. This matters because no funder appears to see the portfolio as a whole, making decision-making harder.

The database reveals aggregate patterns across technologies and types of innovation, but it cannot determine whether they reflect deliberate national priorities or the cumulative outcome of many independent funding decisions. Further, fragmentation tends to leave a gap between research and deployment, often described as the valley of death (Weyant 2011). The portfolio is strongest in early-stage laboratory research, materials development, and component-level innovation, with comparatively less visible activity at the intermediate stage of prototypes, pilot-scale testing, and validation under real operating conditions. Part of this gap may reflect reporting, since institutional reports tend to record such work less consistently (see Limitations), but the pattern is consistent across technology areas. The Research, Development and Innovation (RDI) scheme approved in 2025, an INR 1 lakh crore (USD 10.5 billion) corpus administered through DST that provides long-term, low- or zero-interest financing mainly for private-sector research and innovation, is aimed in part at this gap, though its effectiveness will only become clear over the next few years (Government of India 2025a). Strengthening this middle layer matters because, without mechanisms that support scale-up, validation, and demonstration, promising laboratory research may struggle to reach commercial application, regardless of its scientific quality.

Different stages of innovation require different funding instruments. India's RD&D system largely treats them the same.

Uniform instruments for different kinds of research

Separate from fragmentation, the database points to a second structural feature of the funding system: project sizes are highly uniform across very different kinds of research. Median project sizes vary relatively little across technologies and research types, suggesting that funders are using similar funding instruments to support very different kinds of research. A small investigator-led grant may be entirely appropriate for exploratory materials research or proof-of-concept experiments. The same instrument is far less suited to pilot manufacturing, process development or demonstration projects, which typically require larger budgets, longer time horizons, and sustained collaboration between laboratories, firms, and equipment suppliers.

This raises an important strategic question. Is India's objective to support a broad portfolio of exploratory research across many technology

areas, or to concentrate resources in a smaller number of strategically important capabilities? Both approaches are defensible, but they require different funding architectures. A diversification strategy may be well served by numerous investigator-led grants exploring multiple technological pathways. A capability-building strategy, by contrast, typically requires larger programmes organised around specific technological or manufacturing challenges. India's RD&D system would benefit from a broader mix of funding instruments aligned with different stages of the innovation process.

Is India's objective to support a broad portfolio of exploratory research across many technology areas, or to concentrate resources in a smaller number of strategically important capabilities?



Image: iStock

5 Conclusion

This report set out to ask whether India's public clean energy RD&D system is building the capabilities its ambitions require. Answering that required a descriptive first step: assembling one of the first consolidated pictures of the technologies, institutions, and research activities that make up India's public clean energy research landscape.

The picture that emerges is of a research system that is broad in scope and responsive to India's clean energy transition. Public RD&D spans all six technology categories examined here, with particularly strong activity in solar energy, batteries, and hydrogen, and a smaller body of work on electric mobility. Much of this research is directed towards improving, adapting, and localising technologies for Indian conditions, reflecting the practical challenges of deploying clean energy at scale.

At the same time, the analysis suggests that the questions facing India's public RD&D system are becoming more complex. As national ambitions expand beyond deployment to encompass manufacturing competitiveness, technological capability, and participation in global clean energy value chains, decisions about where to concentrate scarce public research resources become increasingly important. The challenge is therefore not simply one of expanding public RD&D investment, but of determining where deeper domestic capability is needed, where adaptation of existing technologies is sufficient, and how research can connect more effectively with manufacturing, demonstration, and deployment.

The present analysis cannot determine whether the current portfolio represents a deliberate long-term strategy or the cumulative outcome of many individual funding decisions. Nor can it capture the substantial body of private-sector research and innovation that remains outside the scope of publicly available data. These are important limitations. Yet they also point to one of the report's central conclusions: strategic decisions about public RD&D require strategic information. A research system cannot easily be steered if its portfolio cannot be seen clearly.

Strategic decisions about public RD&D require strategic information. A research system cannot easily be steered if its portfolio cannot be seen clearly.

The database presented here should therefore be viewed not as a definitive inventory, but as an evolving evidence base. As it expands and is complemented by improved reporting, international comparison, and deeper engagement with industry and policymakers, it can help move the conversation beyond how much India spends on clean energy RD&D towards a more fundamental question: whether those investments are building the technological capabilities needed to support India's long-term energy, industrial, and climate ambitions.

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Abbreviations

2W/3W	Two- and three-wheelers
ACC	Advanced chemistry cell
AI	Artificial intelligence
ANRF	Anusandhan National Research Foundation
ARAI	Automotive Research Association of India
ARCI	International Advanced Research Centre for Powder Metallurgy and New Materials
BTMS	Battery thermal management system
CCU	Carbon capture and utilisation
CCUS	Carbon capture, utilisation, and storage
CDR	Carbon dioxide removal
CEA	Central Electricity Authority
CEEW	Council on Energy, Environment and Water
CO_2	Carbon dioxide
CPRI	Central Power Research Institute
CSIR	Council of Scientific and Industrial Research
CSP	Concentrated solar power
DBT	Department of Biotechnology
DME	Dimethyl ether
DOE	US Department of Energy
DRDO	Defence Research and Development Organisation
DSIR	Department of Scientific and Industrial Research
DST	Department of Science and Technology
EERE	Office of Energy Efficiency and Renewable Energy (US DOE)
EOR	Enhanced oil recovery
EU	European Union
EUR	Euro
EV	Electric vehicle
FACTS	Flexible alternating current transmission systems
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
FCEV	Fuel cell electric vehicle
FCHEA	Fuel Cell and Hydrogen Energy Association
GDP	Gross domestic product
GW / GWh	Gigawatt / gigawatt-hour
HVDC	High-voltage direct current
IEA	International Energy Agency
IEA-PVPS	IEA Photovoltaic Power Systems Programme
IEEFA	Institute for Energy Economics and Financial Analysis
IESA	India Energy Storage Alliance
IIIT	Indian Institute of Information Technology
IIITDM	Indian Institute of Information Technology, Design and Manufacturing
IISc	Indian Institute of Science
IISER	Indian Institute of Science Education and Research
IIST	Indian Institute of Space Science and Technology
IIT	Indian Institute of Technology
IMPRINT	Impacting Research Innovation and Technology
INR	Indian rupee
IoT	Internet of things
IRENA	International Renewable Energy Agency
ISRO	Indian Space Research Organisation
kW / kWh	Kilowatt / kilowatt-hour
LOHC	Liquid organic hydrogen carrier
MEC	Microbial electrolysis cell
MeitY	Ministry of Electronics and Information Technology

MEMS	Micro-electromechanical systems
MHRD	Ministry of Human Resource Development (now the Ministry of Education)
ML	Machine learning
MNRE	Ministry of New and Renewable Energy
MoE	Ministry of Education
MoEFCC	Ministry of Environment, Forest and Climate Change
MOF	Metal–organic framework
MoP	Ministry of Power
MoPNG	Ministry of Petroleum and Natural Gas
MoSPI	Ministry of Statistics and Programme Implementation
MSME	Micro, small, and medium enterprises
MW	Megawatt
NDC	Nationally Determined Contribution
NISE	National Institute of Solar Energy
NIWE	National Institute of Wind Energy
NIT	National Institute of Technology
NREL	National Renewable Energy Laboratory (US)
NTPC	NTPC Limited (formerly National Thermal Power Corporation)
ONGC	Oil and Natural Gas Corporation
PCB	Printed circuit board
PCM	Phase change material
PEC	Photoelectrochemical
PEM	Proton exchange membrane
PERC	Passivated emitter and rear cell
PLI	Production-Linked Incentive
PM E-DRIVE	PM Electric Drive Revolution in Innovative Vehicle Enhancement
PV	Photovoltaics
R&D	Research and development
RCC	Reinforced cement concrete
RD&D	Research, development, and demonstration
RDI	Research, Development and Innovation (scheme)
RE	Renewable energy
RMI	Rocky Mountain Institute
RPM	Revolutions per minute
SECI	Solar Energy Corporation of India
SERB	Science and Engineering Research Board
SOFC	Solid oxide fuel cell
TCO	Transparent conducting oxide
TOPCon	Tunnel oxide passivated contact
UAV	Unmanned aerial vehicle
UAY	Uchchatar Avishkar Yojana
USD	US dollar
VAWT	Vertical-axis wind turbine

Annexures

Project data was compiled from public disclosures by funding agencies and research institutions. The two major sources of information were:

1. **Institutional annual reports**, consulted directly for the IITs, NITs, IIITs, and other major government research institutions (IISc, IISERs, CSIR laboratories, NISE, CPRI, ARCI, ARAI, SECI, and related bodies).
2. **Funder disclosures and annual reports**, used both as the primary source for the funders listed in Section A.1 below, and as the only source of project-level information for a smaller number of institutions where the project appears in a funder's disclosure but was not directly captured through institutional reporting.

Where information was available from both sources, funder disclosure was treated as primary. Institutional annual reports were used to fill gaps in project descriptions.

A.1 Funding agencies

The bulk of publicly funded clean energy RD&D project data was drawn from the following funders' public disclosures, sanctioned-project lists, and annual reports.

Funder	Source consulted
Department of Science and Technology (DST)	Annual reports; sanctioned projects and programme portals – https://dst.gov.in
Ministry of New and Renewable Energy (MNRE)	Annual reports; R&D project disclosures – https://mnre.gov.in
Council of Scientific and Industrial Research (CSIR)	Annual reports; constituent laboratory disclosures – https://csir.res.in
Ministry of Electronics and Information Technology (MeitY)	Annual reports; project listings – https://www.meity.gov.in
Ministry of Education (MoE) – including UAY, IMPRINT, and legacy MHRD schemes	Annual reports and scheme disclosures – https://www.education.gov.in
Central Power Research Institute (CPRI), Ministry of Power	Annual reports – https://cprims.res.in
Indian Space Research Organisation (ISRO)	Annual reports – https://www.isro.gov.in
Department of Biotechnology (DBT)	Annual reports – https://dbtindia.gov.in
Defence Research and Development Organisation (DRDO)	Annual reports (unclassified sections) – https://drdo.gov.in
Anusandhan National Research Foundation (ANRF)	Programme documents and project sanction lists – https://anrfonline.in
Solar Energy Corporation of India (SECI)	Annual reports – https://www.seci.co.in

A.2 Institutions with directly consulted annual reports

Annual reports and public disclosures were systematically reviewed for all IITs, NITs, IIITs, IISERs, CSIR laboratories and other major public research institutions. Only institutions with at least one project meeting the inclusion criteria are represented in the database.

Institution	Annual report source
Automotive Research Association of India (ARAI), Pune	https://www.araiindia.com
Central Power Research Institute (CPRI), Bangalore	https://cpri.res.in/
Centre for Materials for Electronics Technology (C-MET), Pune and Hyderabad	https://cmet.gov.in
CSIR-Central Electro Chemical Research Institute (CSIR-CECRI), Karaikudi	https://www.cecri.res.in
CSIR-Central Glass and Ceramic Research Institute (CSIR-CGCRI), Kolkata	https://www.cgcri.res.in
CSIR-Central Institute of Mining and Fuel Research (CSIR-CIMFR), Dhanbad	https://www.cimfr.nic.in
CSIR-Central Mechanical Engineering Research Institute (CSIR-CMERI), Durgapur	https://www.cmeri.res.in
CSIR-Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar	https://www.csmcri.res.in
CSIR-Indian Institute of Chemical Technology (CSIR-IICT), Hyderabad	https://www.iict.res.in
CSIR-Institute of Minerals and Materials Technology (CSIR-IMMT), Bhubaneswar	https://www.immt.res.in
CSIR-National Institute for Interdisciplinary Science and Technology (CSIR-NIIST), Thiruvananthapuram	https://www.niist.res.in
CSIR-National Physical Laboratory (CSIR-NPL), New Delhi	https://www.nplindia.org
CSIR-Structural Engineering Research Centre (CSIR-SERC), Chennai	https://www.serc.res.in
Indian Institute of Science (IISc), Bangalore	https://www.iisc.ac.in
Indian Institute of Science Education and Research (IISER), Kolkata	https://www.iiserkol.ac.in
Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram	https://www.iist.ac.in
Indian Institute of Technology (IIT), Bhilai	https://www.iitbhilai.ac.in
Indian Institute of Technology (IIT), Bhubaneswar	https://www.iitbbs.ac.in
Indian Institute of Technology (IIT), Bombay	https://www.iitb.ac.in
Indian Institute of Technology (IIT), Delhi	https://home.iitd.ac.in
Indian Institute of Technology (IIT), Gandhinagar	https://www.iitgn.ac.in
Indian Institute of Technology (IIT), Goa	https://www.iitgoa.ac.in
Indian Institute of Technology (IIT), Guwahati	https://www.iitg.ac.in
Indian Institute of Technology (IIT), Hyderabad	https://www.iith.ac.in
Indian Institute of Technology (IIT), Indore	https://www.iiti.ac.in
Indian Institute of Technology (IIT), Jodhpur	https://www.iitj.ac.in
Indian Institute of Technology (IIT), Kanpur	https://www.iitk.ac.in
Indian Institute of Technology (IIT), Kharagpur	https://www.iitkgp.ac.in
Indian Institute of Technology (IIT), Madras	https://www.iitm.ac.in
Indian Institute of Technology (IIT), Mandi	https://www.iitmandi.ac.in

Indian Institute of Technology (IIT), Palakkad	https://iitpkd.ac.in
Indian Institute of Technology (IIT), Patna	https://www.iitp.ac.in
Indian Institute of Technology (IIT), Roorkee	https://www.iitr.ac.in
Indian Institute of Technology (IIT), Ropar	https://www.iitrpr.ac.in
Indian Institute of Technology (IIT), Tirupati	https://www.iittp.ac.in
Indian Institute of Technology (BHU), Varanasi	https://www.iitbhu.ac.in
Indian Institute of Technology (ISM), Dhanbad	https://www.iitism.ac.in
Indian Institute of Information Technology (IIIT), Allahabad	https://www.iiita.ac.in
Indian Institute of Information Technology (IIIT), Bhubaneswar	https://www.iiit-bh.ac.in
ABV-Indian Institute of Information Technology and Management, Gwalior	https://www.iiitm.ac.in
Indian Institute of Information Technology, Design and Manufacturing (IIITDM), Kanchipuram	https://www.iiitdm.ac.in
Indian Institute of Information Technology, Design and Manufacturing (IIITDM), Kurnool	https://www.iiitk.ac.in
PDPM Indian Institute of Information Technology, Design and Manufacturing (IIITDM), Jabalpur	https://www.iiitdmj.ac.in
International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad	https://www.arci.res.in
Malaviya National Institute of Technology (MNIT), Jaipur	https://www.mnit.ac.in
Motilal Nehru National Institute of Technology (MNNIT), Allahabad	https://www.mnnit.ac.in
National Institute of Solar Energy (NISE), Gurugram	https://nise.res.in
National Institute of Technology (NIT), Agartala	https://www.nita.ac.in
National Institute of Technology (NIT), Arunachal Pradesh	https://www.nitap.ac.in
National Institute of Technology (NIT), Calicut	https://www.nitc.ac.in
National Institute of Technology (NIT), Delhi	https://www.nitdelhi.ac.in
National Institute of Technology (NIT), Durgapur	https://www.nitdgp.ac.in
National Institute of Technology (NIT), Hamirpur	https://www.nith.ac.in
Dr B. R. Ambedkar National Institute of Technology (NIT), Jalandhar	https://www.nitj.ac.in
National Institute of Technology (NIT), Jamshedpur	https://www.nitjsr.ac.in
National Institute of Technology (NIT), Karnataka, Surathkal	https://www.nitk.ac.in
National Institute of Technology (NIT), Kurukshetra	https://www.nitkkr.ac.in
National Institute of Technology (NIT), Meghalaya	https://www.nitm.ac.in
National Institute of Technology (NIT), Puducherry	https://www.nitpy.ac.in
National Institute of Technology (NIT), Raipur	https://www.nitrr.ac.in
National Institute of Technology (NIT), Rourkela	https://www.nitrkl.ac.in
National Institute of Technology (NIT), Sikkim	https://www.nitsikkim.ac.in
National Institute of Technology (NIT), Silchar	https://www.nits.ac.in
National Institute of Technology (NIT), Srinagar	https://www.nitsri.ac.in
National Institute of Technology (NIT), Tiruchirappalli	https://www.nitt.edu

National Institute of Technology (NIT), Uttarakhand	https://www.nituk.ac.in
National Institute of Technology (NIT), Warangal	https://www.nitw.ac.in
National Institute of Wind Energy (NIWE)	https://niwe.res.in
SPRERI – Sardar Patel Renewable Energy Research Institute, Vallabh Vidyanagar	https://www.spreri.org
Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat	https://www.svnit.ac.in
Solar Energy Corporation of India Limited (SECI)	https://www.seci.co.in
Visvesvaraya National Institute of Technology (VNIT), Nagpur	https://www.vnit.ac.in

A.3 Institutions captured via funder disclosures

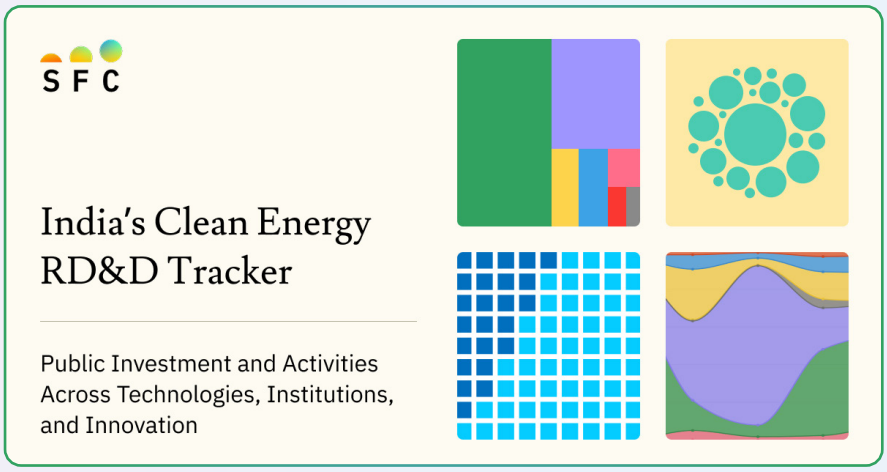
The following institutions appear in the portfolio through funder reports (DST, MNRE, CSIR, and others). Their annual reports were not consulted directly:

- Aligarh Muslim University
- BITS Pilani
- Central University of Tamil Nadu
- Dayalbagh Educational Institute, Agra
- Guru Gobind Singh Indraprastha University, New Delhi
- Kalinga Institute of Industrial Technology (KIIT), Bhubaneswar
- Meghnad Saha Institute of Technology, Kolkata
- Siksha ‘O’ Anusandhan University, Bhubaneswar
- University of Pondicherry
- Uttaranchal University, Dehradun
- APCHEMI Pvt. Ltd., Navi Mumbai (in collaboration with KIIT-TBI, Odisha)
- Waste Reprocessing Society for Technology (WRST), Mumbai and Mount Abu

India's Clean Energy RD&D Tracker

About

The India Clean Energy RD&D Tracker is an interactive database developed alongside this report to provide a consolidated picture of India's publicly funded clean energy RD&D ecosystem. It brings together project-level information from publicly funded research institutions, universities, national laboratories, funding agencies, and government programmes, making it one of the most comprehensive publicly available mappings of India's clean energy RD&D activities to date. The current version of the tracker covers 1,359 publicly funded projects active or initiated between FY2019 and FY2024, representing approximately INR 1,443 crore in declared project funding across over 90 research institutions and six technology categories. The tracker is intended as an evolving resource and will be updated periodically as additional information becomes publicly available.



Using the tracker

The tracker enables users to explore funding patterns, institutional participation, technology priorities, and broader trends across India's public clean energy RD&D system. It is intended to support researchers, policymakers, industry, and other stakeholders seeking to better understand the direction and composition of public investment in clean energy innovation.

The data should be interpreted alongside the limitations outlined in the Methodology section of this report. While the tracker does not capture the full extent of India's clean energy innovation ecosystem, it provides a transparent and consistent evidence base for analysing public RD&D activity and informing future research, policy, and investment decisions.

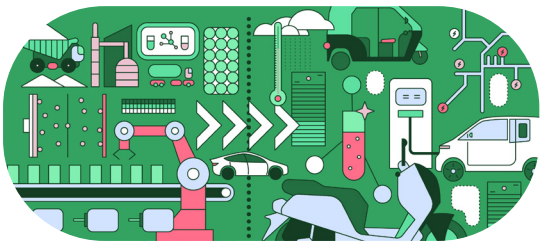
What the tracker includes

Each project has been classified using a consistent framework that allows users to explore India's public RD&D portfolio from multiple perspectives, including:

- Technology category and subcategory
- Funding agency
- Research institution
- Declared project budget (where publicly available)
- Project timeline (where publicly available)
- Degree of innovation (incremental or radical)
- Type of innovation (product- or process-oriented)

Access the tracker and download the project database (CSV)

Related Publications



India's Electric Vehicle Ecosystem: Stuttering Transition or Strategic Reorientation?



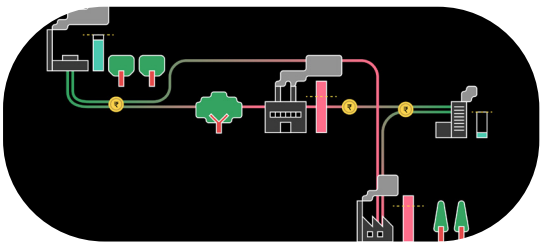
India's Solar Crossroads: Borrowing Innovation or Building Its Own?



India's Green Hydrogen Push: Engineering for Today or Innovating for Tomorrow?



India's Energy Storage RD&D Bet: Why Batteries Dominate, and What That Means for the Future



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