

The industrial alchemy of science-based entrepreneurship: a comprehensive analysis of the Indian innovation ecosystem



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The emergence of science-based entrepreneurship as a distinct pillar of industrial strategy reflects a fundamental recalibration of how value is created and sustained in the modern global economy. Innovation, in this context, is no longer to be viewed merely as the generation of ideas, but as the disciplined act of creating new value, typically manifested through enhanced productivity, superior cost structures or novel revenue streams.

Informal surveys were conducted by the author in 2017 and 2026 with research and development (R&D) leaders and innovation practitioners in India (Katragadda, 2018; Katragadda, 2026). These surveys represent indicative practitioner perspectives rather than being a representative assessment of the full Indian innovation ecosystem. The 2017 survey was based on an informal LinkedIn question asking respondents what aspects of innovation they would like to see covered in the author's book on the subject, generating more than 200 responses. The 2026 survey was a structured Google Forms survey focused on science-based innovation in India and involved targeted outreach to R&D leaders and practitioners, resulting in 40 responses. Together, the findings from these surveys reflect a clear maturing of India's science-based entrepreneurship landscape, with a notable shift from consumer digital models toward applied, engineering-led domains such as industrial AI, health care, advanced manufacturing, and energy systems. Respondents consistently identified India's structural strengths to be its large domestic market, diversity of real-world problems and depth of technical talent, making the country a large-scale setting for testing and adapting science-based innovation. Importantly, the definition of innovation itself is evolving, with success increasingly measured through customer adoption, revenue generation and pilot-to-scale conversion rather than patents or publications.

The 2026 survey also highlights a widely acknowledged but narrowing gap in the "translation" of science into enterprise, with key challenges centered on business model development, productization of research and access to patient capital. Encouragingly, industry sentiment reflects a growing awareness of the need for longer gestation cycles and iterative, incremental innovation, even as educational systems and institutional interfaces – particularly industry-academia collaboration – continue to lag. Concerns around intellectual property (IP) are becoming more pragmatic, balancing protection with speed to market, although operational frictions remain. Also, unlike the previous decade, which was dominated by consumer internet and platform businesses, recent years have seen an accelerated formation of deep-tech startups and industrial spin-offs in industrial AI, semiconductors, medtech, energy systems, defense, and space technologies. Such ventures are frequently rooted in translational research emerging from institutions, such as the IITs, IISc, ISRO-linked programs, national laboratories, and industrial R&D ecosystems. Overall, the findings point to an ecosystem in forward motion,

one that has moved beyond the question of whether India can innovate toward how it can systematically and reliably convert scientific capability into scalable, competitive ventures.

The paradox of discovery: navigating the friction of translation

A primary insight derived from industry practitioners is the persistent gap between the “romance of discovery” and the “grind of translation.” While the initial breakthrough in a laboratory setting often attracts significant attention, various successful endeavors have demonstrated that the vast majority of time, effort and capital is devoted to the transition from an invention to a viable solution that is manufacturable, reliable, regulatory-compliant and desirable at scale. This translation phase is where the leading innovative nations hold a significant advantage, possessing the distribution networks, quality control systems and lived understanding of market constraints necessary to navigate the complexity of productization.

However, these same industrial attributes frequently manifest as barriers. The discipline required for large-scale operations can harden into bureaucracy, short-term financial focus and a pervasive risk aversion. Consequently, science-based entrepreneurship within an industrial context requires a delicate balancing act, leveraging the formidable assets of an established firm without allowing institutional inertia to stifle the development of new ventures. This tension is particularly acute in India, where national R&D expenditure has historically remained low (Table 1), currently hovering around 0.64 percent of the gross domestic product (GDP) (Gargeyas and Sahni, 2025). This low investment level is compounded by a heavy reliance on public funding, which accounts for two-thirds of all R&D spending and is largely concentrated in approximately 300 national autonomous research institutions, leaving the private sector and universities with a smaller share of the innovation investment (Gargeyas and Sahni, 2025).

Technology readiness levels and the Valley of Death

The “grind of translation” involves moving a technology through various technology readiness levels (TRLs). Whereas universities and research labs are proficient at reaching TRL 3 or 4 (laboratory validation), the transition to TRL 7, 8 and 9 (system prototype demonstration and actual operations) is where most science-based ideas falter (Gargeyas and Sahni, 2025). Within industrial settings, failure is often attributed to the absence of dedicated mechanisms to bridge TRL levels. Industry professionals note that, while idea creation is celebrated, systemic support for the subsequent phases, such as manufacturing scale-up, certification and clinical validation, is often insufficient (Gargeyas and Sahni, 2025). This is particularly true for science-based ventures, which typically require a longer gestation period than software-only startups, demanding patient capital and long-term institutional commitment (Katragadda, 2018; Katragadda, 2026).

Table 1 India R&D investments and associated innovation data

Metric (2025–2026 data)	Indian innovation landscape (approximation)
R&D spend as % of GDP	0.64%
Public sector share of R&D	~66.7%
Private sector R&D contribution	~33.3%
Number of national research labs	>300
Global Innovation Index ranking (2015)	81
Global Innovation Index ranking (2024)	39
Global Innovation Index ranking (2025)	38

Sources: Gargeyas and Sahni (2025); Cornell University, INSEAD and WIPO (2015); WIPO (2024, 2025).

Innovation as a progression of mindsets

A useful framework for analyzing the innovation lifecycle is to view it as a progression of distinct mindsets rather than a single event. The author identifies three critical phases: the freedom to create phase; a phase demanding a passion for nurture; and a phase calling for the detachment necessary to change course based on empirical evidence (Katragadda, 2018).

Freedom to create and a passion for nurture

In many industrial environments, the first phase, the freedom to create, is frequently over-emphasized. Organizations often launch idea-creating campaigns, hackathons and internal suggestion schemes to generate a high volume of concepts (Katragadda, 2018). However, the second phase – the passion for nurture – is consistently under-resourced. Nurturing a science-based venture requires patient talent, protected time and a willingness to execute pilots that may not demonstrate profitability within the first few quarters (Katragadda, 2018). Without these resources, even the most promising scientific insights are often abandoned prematurely. Such neglect often stems from a fundamental misunderstanding of the time constraints involved in deep-science ventures compared to digital-only products (Katragadda, 2018).

The discipline of detachment

The third phase – the detachment to change course – is perhaps the most culturally challenging for established firms. Detachment requires an objective, evidence-based review in order to overcome cultural resistance to challenging the hierarchy and sunk-cost biases. It demands that individuals and leaders challenge established ownership and navigate hierarchical power structures. When practitioners discuss the gap between innovation and execution, they are often pointing to a lack of mechanisms that reliably facilitate the transition between these mindsets. A failure to institutionalize detachment often results in “zombie projects” that continue to consume resources long after empirical evidence suggests they are no longer viable (Katragadda, 2018).

The middle ground: engineering frontier science

A recurring question in industrial discourse is whether effective innovation requires a paradigm shift or whether incremental advances are equally valuable. Practitioners suggest that, while both are necessary, they behave differently within an organization (Katragadda, 2018; Katragadda, 2026). Incremental innovation can compound over time through systematic repetition, similar to continuous improvement processes. It is typically easier to fund, measure and adopt within existing operational frameworks (Katragadda, 2018; Katragadda, 2026). Paradigm shifts, while capable of resetting entire industries, are rarer, involve significantly longer timelines and are highly sensitive to market timing (Katragadda, 2018; Katragadda, 2026).

Science-based entrepreneurship

Science-based entrepreneurship typically occupies the space between a paradigm shift and incremental advances. It often begins with a step-change in technical capability. Examples include a breakthrough in materials science or a novel sensing method. However, a continuous series of engineering refinements are required to make the solution robust, affordable and market-ready (Gargeyas and Sahni, 2025). For India, an important opportunity lies in mastering this “middle ground.” By engineering frontier science into reliable products (not necessarily paradigm shifting to begin with) designed for large, cost-sensitive markets, Indian firms can create a competitive advantage (Gargeyas and Sahni, 2025).

Advanced frugal innovation: beyond “jugaad”

This approach moves beyond the traditional “jugaad” model of improvisation and toward a disciplined form of “advanced frugal innovation” (AFI). AFI focuses on achieving high-quality functionality using significantly fewer resources (Katragadda, 2018; Katragadda, 2026). Unlike grassroots improvisation, AFI utilizes the most accurate scientific tools and employs rigorous engineering to achieve its objectives (Rao, 2025). AFIs are designed to minimize material and energy requirements, thereby reducing both costs and environmental impact, while

maintaining or enhancing product quality. The technical methodology for AFI revolves around the stochastic frugal approach (SFA) that integrates deterministic and stochastic techniques to optimize resource consumption (Rao, 2025). This approach explicitly accounts for uncertainties like climate change or mechanical stress through Monte Carlo simulations and machine learning, ensuring that frugal products remain highly reliable even under marginal conditions of overloading (Rao, 2025). Examples of such AFIs include portable electrocardiogram (ECG) machines and the Inter-University Accelerator Centre (IUAC, Delhi)-developed tabletop particle accelerators, requiring cutting-edge research in biomedical engineering and particle physics.

Corporate R&D expenditure and strategic investment

The commitment of large Indian corporations to R&D is a critical indicator of the country's science-based entrepreneurial ecosystem. Major players have significantly increased outlays in order to pivot toward AI, electric vehicles (EVs) and advanced materials. Tata Consultancy Services (TCS) has moved beyond a services model to become a digital transformation partner, crossing the USDUSD 30 billion revenue milestone in financial year (FY) 2024–2025 (Tata Consultancy Services, 2025). Driven by an annualized AI services revenue of USD1.8 billion, TCS has maintained a consistent R&D commitment, having invested an average of approximately USDUSD 40 million over the last five fiscal years to develop platforms like Rapid Outcome AI for autonomous manufacturing (Tata Consultancy Services, 2025). Tata Motors has seen an even more aggressive rise in investment, with consolidated R&D spend jumping from INR15,339 crore in FY22 to over ₹33,000 crore in FY25 (Tata Motors, 2025). This capital-intensive pivot supports “Project Aalingana,” which aims for net-zero emissions by 2040/2045 and includes establishing 60GWh of battery capacity through Agratas (a global battery business within the Tata Group). Tata Steel is reimagining the steel value chain with a consolidated R&D spend of ₹953 crore, focusing on low-emission manufacturing and the production of advanced materials like graphene (Tata Steel, 2025). Mahindra & Mahindra (M&M) follows a federated structure that allows its “growth gems,” such as Last Mile Mobility and Mahindra Susten, to operate with the agility of a startup while leveraging group R&D, which reached a peak cost of ₹2,741 crore recently (Mahindra & Mahindra, 2025). Similarly, Infosys has transitioned to an “AI-first” enterprise, training over 300,000 employees in AI and peaking its R&D expenses at ₹1,059 crore to drive agentic AI deployment through platforms like Topaz (Infosys, 2025). Such investments demonstrate a shift wherein corporate R&D is no longer a peripheral activity but instead the core driver of global competitiveness.

Translating science: deep-tech success stories

The practical translation of science into industrial ventures is increasingly evidenced by a new generation of deep-tech startups and academic spin-offs. TriNano Technologies, a SINE IIT Bombay-incubated startup, has successfully commercialized patented nano-coatings for solar panels that increase energy output by ~4 percent and reduce cleaning needs by 55 percent (TriNano Technologies, n.d.). Within the aerospace sector, Skyroot Aerospace and Agnikul Cosmos (incubated at IIT Madras) have pioneered private space exploration in India, with Agnikul launching a rocket featuring a single-piece 3D-printed engine (Skyroot Aerospace, n.d.; Agnikul Cosmos, n.d.). Other notable examples include Pandorum Technologies, which emerged from C-CAMP to lead in tissue engineering and 3D bioprinting, and Log9 Materials, which focuses on advanced battery chemistry. The biotechnology space is also seeing a “lab-to-market” pipeline through “biofoundries,” such as the one at ICGEB New Delhi, which supports startups like Ahammune Biosciences and ImmunoAct in developing sustainable alternatives and therapeutics. These ventures illustrate India's broadening from services-led innovation toward science-led industrial innovation.

Culture, organizational design and risk

Organizational design and culture serve as the decisive variables in the success of science-based entrepreneurship. Industry practitioners frequently emphasize that the personal cost of failure in industrial firms remains prohibitively high, where career risks often outweigh specific project risks. This environment inevitably drives risk aversion, pushing employees toward safe, incremental extensions of existing products rather than the creation of high-uncertainty, science-led ventures. A critical indicator of an organization's readiness for such ventures is its ability to distinguish between “careless failure” resulting from poor execution

and “well-designed failure,” which is the necessary price of exploration in an uncertain scientific landscape. Beyond failure management, reward systems and hierarchy play significant roles in shaping the innovation lifecycle. Traditional reward systems often penalize long-gestation science projects through an emphasis on short-term milestones, while rigid hierarchies and concentrated decision-making authority can stifle the questioning required for scientific breakthroughs. To combat these barriers, leading firms have institutionalized new cultural frameworks. The Tata Group’s “Dare to Try” award (Tata Innovista, n.d.) recognizes those novel ideas that did not achieve the desired result, thereby helping employees overcome the vulnerability and “shame” of being wrong, while ensuring that the organization learns from every such attempt. Similarly, Mahindra’s “Rise” philosophy (Mahindra Group, n.d.) encourages “well-reasoned risk-taking,” celebrating both success and failure as vital components of a growth-oriented learning process.

Strategic role of intellectual property

Intellectual property occupies a complex position in science-based entrepreneurship. While patents provide legal protection, in many sectors, speed and execution constitute the more effective “moat” (Gargeyas and Sahn, 2025). Effective IP management involves recognizing that ultimate value is derived from the ability to bring a science-based solution to market more efficiently than competitors (ANRF, 2026).

Recent reforms have significantly augmented India’s IP framework, with a 180 percent increase in patent filings between 2020–2021 and 2024–2025 (OPPI, 2025). The examination period for patents has been reduced from 48 months to an average of 31 months, supported by 95 percent online filing (Centre for Policies, Laws and Agenda, n.d.). However, gaps remain such as the absence of “data exclusivity” laws for pharmaceutical and agro-chemical industries, which creates regulatory uncertainty (Centre for Policies, Laws and Agenda, n.d.).

India’s progress is reflected in the Global Innovation Index (GII), where the country has moved upward from a rank of 81 in 2015 to ranking 38 in 2025, driven by improvements in knowledge and technology outputs and market sophistication (Cornell University et al., 2015; WIPO, 2025).

The India dimension: scale as a laboratory

India’s specific conditions, including its scale, cost pressures and diversity of needs, create a large-scale testbed for science-based innovation. The Indian innovation agenda is increasingly aligned with national challenges (Table 2) such as health, agricultural resilience and energy transition (Press Information Bureau, 2026a).

Table 2 India: national challenges, innovation opportunities and technology levers

National challenge	Innovation opportunity	Key science/tech lever
Public health	Affordable diagnostics and drugs	Biotech, biosimilars, internet of things (IoT)
Energy transition	Green hydrogen and storage	Materials science, chemical engineering
Agricultural resilience	Precision farming and bio-fertilizers	Bio-agri, remote sensing, AI
Environmental pollution	Carbon capture and waste-to-energy	Advanced materials, microbiology

“Lifetech” sector and biotech hubs

The biotechnology sector serves as an important example of science-based entrepreneurship (SBE) in India. With a goal of creating a USD100 billion bioeconomy, organizations like BIRAC have established a foundation for startups through mentorship and funding tools like the Biotechnology Ignition Grant (BIG) (BIRAC, 2026). The number of biotech startups has surged from just 50 in 2014 to nearly 11,000 by 2025 (BIRAC, 2026). Major initiatives like the ₹10,000 crore “Biopharma SHAKTI” program (Press Information Bureau, 2026a) are designed to strengthen the end-to-end ecosystem for biologics and biosimilars, moving away from simple generic drug manufacturing toward high-value innovation (Press Information Bureau, 2026a).

Institutional reform and the ANRF

A critical bottleneck in India's innovation ecosystem has been the relative isolation of public research institutions from the private sector (ANRF, 2026). To address this, the Government of India established the Anusandhan National Research Foundation (ANRF) to catalyze the R&D ecosystem (ANRF, 2026).

ANRF policy packages

The ANRF is focused on three main areas:

1. **Closing financing gaps:** Providing grants and non-dilutive loans to startups and small and medium-sized enterprises to bridge the "Valley of Death."
2. **Increasing infrastructure access:** Creating structures enabling private entities to rent scientific infrastructure within public laboratories.
3. **Developing human capital:** Strengthening industry-academia linkages through private sector fellowships and "professors of practice" roles (ANRF, 2026).

The ANRF targets ₹50,000 crore in research funding between 2023 and 2028, with ₹20,000 crore allocated for FY 2025–2026 through the Research, Development and Innovation (RDI) scheme (DST, 2023). This scheme supports high-TRL projects in energy transition, robotics and synthetic biology (DST, 2023).

Financial ecosystem and market access

Science-based entrepreneurship requires "patient capital" that understands the unique risk profiles and longer gestation periods of technical translation. Programs like the Biotechnology Ignition Grant (BIG) and technology development funds from the Defence Research and Development Organisation (DRDO) provide critical support during early research stages (ANRF, 2026).

The Government e-Marketplace (GeM) has emerged as an important mechanism in providing market access for science-based ventures. By streamlining public procurement processes, GeM has enabled startups to fulfill orders worth ₹35,950 crore, with cumulative order values crossing ₹54,005 crore by FY 2025–2026 under the SWAYATT initiative (Press Information Bureau, 2026b). This robust procurement ecosystem provides a stable demand base that encourages further private investment. Specific initiatives like Startup Runway 2.0 have further enhanced access by increasing visibility for micro and small enterprises, which accounted for 44.8 percent of the total order value in 2025–2026. Additionally, the Startup India program's policy of exempting startups from tender fees has been a significant driver of commercial success, with 72.5 percent of participating entrepreneurs reporting increased sales as a result (Saha *et al.*, 2025).

Conclusion: a shift toward disciplined innovation

The transition from "jugaad" to repeatable, disciplined innovation represents the next stage of India's economic evolution. The emergence of "lifetech," "advanced frugal innovation" and systemic support through the ANRF indicate a shifting paradigm wherein Indian entrepreneurs are increasingly confident in tackling complex scientific problems. By fostering a culture of advanced frugal engineering and institutionalizing the mechanisms of translation, India may be better positioned to move from being a source of technical talent to a source of industrial ventures, ensuring that scientific capability is consistently converted into sustainable market value. The mapping of innovation frictions reveals that the opportunity for India to strengthen its innovation position depends on its ability to convert unique national challenges into venture scale, leveraging its immense demographic and geographic landscape to become a large-scale testbed for science-based innovation.

References

- Agnikul Cosmos (n.d.). Agnikul Cosmos, company website. Available at: <https://agnikul.in>.
- ANRF (Anusandhan National Research Foundation) (2026). *ANRF Programs: A Compendium*. New Delhi: ANRF. Available at: https://serb.gov.in/assets/pdf/Final_Compendium_04-02-26.pdf.
- BIRAC (Biotechnology Industry Research Assistance Council) (2026). *India BioEconomy Report 2026: USD195.3 Billion Milestone*. New Delhi: BIRAC, Department of Biotechnology. Available at: https://ableindia.in/manage/images/resourceuploads/_IBER%202026_compressed.pdf.
- Centre for Policies, Laws and Agenda (n.d.). India's National Intellectual Property Rights Policy: A Comprehensive Framework for Innovation and Development. National University of Study and Research in Law, Ranchi. Available at: <https://nusrlranchi.ac.in>.
- Cornell University, INSEAD, and World Intellectual Property Organization (WIPO). (2015). *Global Innovation Index 2015: Effective Innovation Policies for Development*. Ithaca, NY: Cornell University. DOI: <https://doi.org/10.34667/tind.28212>.
- DST (Department of Science and Technology) (2023). *Research and Development Statistics 2022–23*. New Delhi: NSTMIS, Government of India.
- Gargeyas, A. and K. Sahni (2025). Building India's Innovation Economy: Catalyzing Private R&D Activity Through the ANRF. *M-RCBG Associate Working Paper No. 255*. Cambridge, MA: Harvard Kennedy School, Mossavar-Rahmani Center for Business and Government.
- Infosys (2025). *Integrated Annual Report 2024–25: AI-first Enterprise*. Bengaluru: Infosys Limited.
- Katragadda, G. (2018). *S.M.A.S.H. Innovation: Smashing the Hand–Mind–Market Barrier*. New Delhi: Wiley India.
- Katragadda, G. (2026). Unpublished primary research conducted for the *Global Innovation Index* chapter.
- Mahindra & Mahindra (2025). *Integrated Annual Report 2024–25: Driving the Future of Mobility*. Mumbai: Mahindra & Mahindra Ltd.
- Mahindra Group (n.d.). The Mahindra Group official website: Together we rise. Available at: <https://www.mahindra.com>.
- (2026). *Economic Survey 2025–26*. New Delhi: Government of India. Available at: <https://www.indiabudget.gov.in/economicsurvey>.
- OPPI (Organisation of Pharmaceutical Producers of India) (2025). *Essays on Innovation*. New Delhi: OPPI.
- PIB (Press Information Bureau) (2025). Cabinet approves Research, Development and Innovation (RDI) Fund of Rs. 1 lakh crore. New Delhi: Ministry of Science & Technology.
- PIB (Press Information Bureau) (2026a). Bio Pharma SHAKTI scheme. New Delhi: Ministry of Chemicals and Fertilizers, Department of Pharmaceuticals. Available at: <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2237416®=3&lang=1>.
- PIB (Press Information Bureau) (2026b). GeM celebrates seven years of SWAYATT initiative to promote inclusive public procurement. New Delhi: Ministry of Commerce & Industry. Available at: <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2236036®=3&lang=1>.
- Rao, B.C. (2025). A novel stochastic approach for reliable design of advanced frugal products. *Scientific Reports*, 15(1), 25724. DOI: <https://doi.org/10.1038/s41598-025-10204-w>.

Saha, D., T. Singh, G. Maheshwari, K. Arora, K., Kartik and K. Kapoor (2025). On recent advances in public procurement: An exploration of the Government e-Marketplace in India. *Public Administration & Development*, Blackwell Publishing, 45(4), 361–376. DOI: <https://doi.org/10.1002/pad.2113>.

Skyroot Aerospace (n.d.). Skyroot Aerospace, company website. Available at: <https://www.skyroot.in>.

Tata Consultancy Services (TCS). (2025). *Consolidated Financial Results for the Year Ended March 31, 2025*. Mumbai: TCS.

Tata Innovista (n.d.). Tata Innovista, company website. Available at: <https://tatainnovista.com>.

Tata Motors (2025). *Integrated Annual Report 2024–25: Sustainable Mobility Solutions*. Mumbai: Tata Motors Limited.

Tata Steel (2025). *Integrated Report & Annual Accounts 2024–25: Reimagining Steel*. Mumbai: Tata Steel Limited.

TriNano Technologies (n.d.). TriNano Technologies, company website. Available at: <https://trinano.co>.

WIPO (World Intellectual Property Organization) (2024). *Global Innovation Index 2024: Unlocking the Promise of Social Entrepreneurship*. Geneva: WIPO. DOI: <https://doi.org/10.34667/tind.50062>.

WIPO (World Intellectual Property Organization) (2025). *Global Innovation Index 2025: Innovation at a Crossroads*. Geneva: WIPO. DOI: <https://doi.org/10.34667/tind.58864>.

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