सत्यमेव जयते
NITI Aayog

NITI Frontier Tech Hub

FUTURE FRONT:

QUARTERLY FRONTIER TECH INSIGHTS

December 2024

FOREWORD

BVR Subrahmanyam

CEO, NITI Aayog

As India stands at the cusp of an unprecedented era of transformation, driven by the rapid evolution of frontier technologies like Artificial Intelligence and Bioengineering, the NITI Frontier Tech Hub is proud to launch a quarterly Insights series, titled **FutureFront: Quarterly Perspectives on Frontier Tech**. This initiative aims to demystify these groundbreaking technologies, offering a high-level understanding of key trends, innovations, and adoption—both globally and within India.

In this inaugural edition, we focus on the fast-evolving landscape of AI and Bioengineering. These technologies are swiftly transitioning from experimental concepts to mainstream disruptors. They are not merely tools for efficiency but hold the potential to become transformative enablers of a new growth paradigm, with the potential to redefine economies, drive social change, and create inclusive opportunities for all.

FOREWORD

Debjani Ghosh

Distinguished Fellow, NITI Aayog

Future Front: Quarterly Perspectives on Frontier Tech is a high-level insight series designed to provide a snapshot of the latest trends and developments shaping the frontier tech ecosystem globally. By offering concise overviews and insights, the series aims to build a foundational understanding of frontier technologies, highlighting their potential opportunities and risks.

As part of the **NITI Frontier Tech Hub Charter**, this quarterly series serves as a starting point, introducing key technologies and their implications for economic growth and societal development. In-depth workstreams will take a deeper dive into assessing their impact on key areas like Citizen Empowerment, Industry Transformation, Governance Transformation and Global Leadership, providing more detailed assessments and strategic recommendations.

Future Front: Quarterly Frontier Tech Insights

Artificial Intelligence (AI)

Dec 2024

AI: Recent breakthroughs and emerging trends (1 of 4)

Theme	Description	Examples
Emergence of Multimodal Models	Multimodal AI refers to machine learning models capable of **processing and integrating information from multiple modalities or types of data e.g.** text, images, audio, video and other forms of sensory input.	• **Open AI's GPT-4** is a large multimodal model (accepting text or image inputs and outputting text) that can solve difficult problems with greater accuracy due its broader general knowledge and advanced reasoning capabilities. • **ImageBind by Meta** allows users to provide data in one modality, e.g., audio – and find related documents in different modalities, e.g., video. • **Emu3 by** Beijing Academy of Artificial Intelligence is a multimodal model that unifies understanding and generation of text, image, and video modalities.
Improvements in performance of small language models	2024 saw an **explosion of small specialized models** that have been distilled using outputs from larger models. These models offer greater efficiency and accuracy by **specializing in narrow tasks while reducing costs drastically.**	• Popular small language models **are Mistral's 7B, Microsoft's Phi-2, and Google's Gemma.** • **Mistral 7B has a lower latency compared to average models,** with an estimated Time To First Token (TTFT) of ~0.33 to 0.36 seconds.
Model Reasoning Ability	**Large Language Models (LLMs) ability to be used for reasoning is an ongoing debate.** OpenAI claims that these models are capable of reasoning but skepticism remains around their depth of "true" reasoning versus pattern-matching	• The newly **released OpenAI o1** is a new series of AI models which leverages multiple chain-of-thought processing and is **designed to spend more time thinking before they respond.** It is designed **to address complex tasks** in fields such as science, mathematics, and coding**.** • **Anthropic's Claude 3 models** provide high accuracy and contextual understanding, with capabilities in reasoning, content creation, and multimodal processing **.**

AI: Recent breakthroughs and emerging trends (2 of 4)

Theme	Description	Examples
Greater adoption of open source models	Powerful **open-source models are challenging their closed-source counterparts** in performance and developer adoption as they provide developers with easy **access to build innovative tools and study complex systems.**	• Meta's **Llama 3, an open-source model excels in reasoning tasks and can follow instructions more effectively**, which is crucial for applications such as chatbots and virtual assistants. It can be fine-tuned to **meet the needs of specific industries, such as healthcare, finance, and research**.
AI focused data centers	**AI data centers** are rapidly evolving facilities specifically designed to accommodate the growing computational needs of artificial intelligence applications. Significant financial commitments are being made globally, with projections estimating **spending on AI data centers to reach between $80 billion and $100 billion by 2025.** With the rising concern over the environmental impact of AI operations, there is a focus on developing energy-efficient data centers that minimize carbon footprints while maximizing computational power.	• Meta announced plans to **invest $10 Bn in a new artificial intelligence data center in northeast Louisiana by 2030**. The facility is the largest of more than 20 Meta data centers around the world and can process the vast amounts of data required to support digital technologies, including Artificial Intelligence (AI) workloads. • **Microsoft and OpenAI** are building a massive $100 billion data center that can enable the most powerful AI offerings and models for the future, including a next-level AI supercomputer—set to be operational in 2028. • As AI grows, there is **increasing urgency to make data centres greener**. Cos like Microsoft, Google and Amazon have all secured **nuclear energy deals worth billions of dollars** in recent months to support the next generation of AI applications without compromising environmental goals..

AI: Recent breakthroughs and emerging trends (3 of 4)

Theme	Description	Examples
Hardware Acceleration in Applied AI	To **train large, complex models and operate them in real time, organizations are shifting toward specialized hardware** such as graphics processing units (GPUs), field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), etc.	• Nvidia's **Blackwell GPU architecture is a next-generation GPU designed to accelerate computing and enable real-time generative AI**. Organizations expected to adopt Blackwell are AWS, Dell Technologies, Google, Meta, Microsoft, OpenAI, Oracle, Tesla and xAI.
Agentic systems amplifying the impact of Gen AI	Agentic AI Systems **provide autonomous decision-making and problem-solving capabilities** with minimal human intervention. These frameworks allow better performance by defining specific tasks for each LLM instance and giving tools to the LLM.	• **Microsoft's AutoGen** allows developers to build LLM applications via multiple agents that can converse with each other. • **Microsoft's Magentic-One**, generalist multi-agent system for solving open-ended web and file-based tasks, developing agents that can complete tasks that people encounter on daily basis. • **OpenAI's Swarm**, is an experimental framework that provides developers with a blueprint for creating interconnected AI networks. • **CrewAI** is an opensource software available to build agentic systems.
Policy and Regulation	Globally, there are **concerns about a potential lack of transparency and regulations in the functioning of AI systems** – Issues of bias and fairness, IP infringements, privacy violations, third-party risk, security concerns , etc.	• **China-** Implemented regulations for generative AI services, **emphasizing algorithm transparency**, data security, and intellectual property compliance • **EU**: First to launch an AI law in effect-European Union's (EU) Artificial Intelligence (AI) Act 2024 which categorizes AI applications by risk and applies different rules to each category, targeting high-risk AI systems with **penalties of up to 7% of global revenue** • **UK: Regulatory innovation office** to **streamline regulatory proce**sses (e.g., accelerate approvals, facilitate inter-regulator collaborations) for businesses on technologies like AI in key sectors.

AI: Recent breakthroughs and emerging trends (4 of 4)

Category	Description	Examples
Infrastructure Development	Robust infrastructure serves as backbone for successful deployment and operation of AI/ Gen AI. Developments are needed to increase computational power, enhance scalability and flexibility, and support comprehensive data management, to drive innovation and ensure robust performance across sectors.	• **US-** OpenAI shared its five-pillar blueprint for building AI infrastructure in the U.S; Global AI Infrastructure Investment Partnership to raise $80 Bn - $100 Bn to build data centers and energy grids to power them. • **Europe-** The EuroHPC Joint Undertaking has a budget of **€ 7 Bn for the period 2021-27 to develop, acquire, and deploy advanced supercomputer** • **India:**India AI mission aims to establish a robust AI computing infrastructure in India to support the development and testing of AI systems, allocated $600 Mn to procure GPUs and provide subsidised compute capacity to Indian startups. ; $20 Bn for green integrated data center parks in Maharashtra in upcoming years • **UAE**: MGX Initiative, backed by Mubadala and G42, aims **to manage $100B+ in AI and semiconductor assets**, focusing on AI infrastructure, semiconductors, and core AI technologies • **UK: Microsoft has committed £2.5 Bn** to **double AI data center capacity** with 20,000 GPUs by 2026
Skilling and Collaboration	Skilling efforts are needed to ensure workforce proficient in advanced technologies and foster innovation through shared expertise. Efforts (with govt and private collaboration) can drive effective integration of AI solutions, enhance problem-solving capabilities, and promote sustainable growth across industries.	• US: Google's **$15 Mn grants** for Center for Federal AI, support AI education for 1L+ state and local employee • **France: €4 Bn ($4.23 Bn) investment to train 1 Mn people and support 2,500 startups** by 2027 • Singapore: $**20 Mn allocated for AI-focused scholarships and internships** under the SG Digital Scholarship • **India**: **MSDE** partners with Meta for AI Assistant in Skill India Mission and 5 **Centers of Excellence in NSTIs**; **IndiaAI** and Meta announced establishment of Center for Generative AI, Srijan and launch of the "YuvAi Initiative for Skilling and Capacity Building" in collaboration with **AICTE** • Global: NVIDIA joined the U.S. Partnership for Global Inclusivity on AI, **committing $10M in free training and resources** alongside tech giants to support **AI-driven growth in developing countries**

Potential opportunities for significant impact in India (1 of 2)

AI can improve performance in every area of business, across sales, marketing, distribution and supply chain, manufacturing, and support services like finance, HR and IT.

- **Right product, right place, right time**. AI can use geo-spatial data (e.g., type of shops in a market), market trends, and other data sets, to predict sales of products in micro-markets and across channels (online or offline). This improves sales, reduces discounting for clearance, and reduces wastage.
- **Yield, energy, throughput, and quality optimization**. AI can use granular data from manufacturing, agriculture, mining and other "production" processes to find the most optimal settings for the process. Such applications have led to improved efficiency of conversion of raw inputs to final product, lowered energy consumption and overall wastage.
- **Personalization**. AI can use data reflecting customer behaviour to recommend products and services that are most likely to suit the customer's preferences. This has led to increased sales and higher customer satisfaction. This has also lowered the customer acquisition costs for niche, small-scale brands of products and services.
- **Service operations excellence**. AI can be used to improve response time and reduce errors in service processes like application processing in banks or matching candidate profiles to job vacancies or responding to queries about a company's products. AI achieves these outcomes by facilitating assimilation of information across multiple sources, reading documents, creating drafts, providing multi-modal (e.g., text, image, and voice) interfaces, and calculating risk scores.

India can increase its share of net exports related to AI by meeting new demands emerging from global interest in AI, improving domestic capabilities and offering them to international markets. This will also be important to mitigate the risk that AI poses to some of the existing industries and jobs.

- **Meeting global demand for new services for AI applications**. Rise in global demand for AI services, especially with generative AI, is creating new opportunities, e.g., tagging and management of large documents to prepare them for consumption by AI applications, or validation of outputs from gen AI systems that are prone to "hallucinations" or management of cloud-based gen AI applications. These services will continue to require "human-in-the-loop" in the near term. India is well poised to capitalise on this opportunity because of the strengths in IT services, BPO, and KPO, amongst others.

Potential opportunities for significant impact in India (2 of 2)

- **Sovereign AI stack to support applications**. India can increase domestic capabilities in all parts of the technology stack (e.g., AI models, data centres, compute capabilities, semiconductor value chain for processors, and integrated services provided through cloud platforms). This will boost domestic industry, reduce spending on "imported" services, and create opportunities to offer these to the global market. Abu Dhabi has created Group 42 as a state-backed private company towards the same goal.

AI can be used to increase the quality and coverage of services to citizens, in a cost-effective manner. India can utilize its strengths in mobile connectivity, low data costs, and existing programs for healthcare, education, and others, to improve the outcomes in a cost-effective manner. This could also open new opportunities for economic value creation for Indian companies.

- **Healthcare**. AI can be used to provide information to every Indian, in the language of their preference, irrespective of their level of literacy, in the privacy and comfort of their place of stay. It can also be used to help health workers regularly refresh and improve their knowledge and skills, while being on their phones. It can be used to improve diagnosis of diseases and improve supply chain operations to reduce stock-outs or wastage.
- **Education**. AI can be used to provide educational content to students, in an engaging and multi-modal manner, tailored to their needs, in a cost-effective manner. It can also be used to support teachers in preparing lessons and conducting evaluations. South Korea has announced a similar program to strengthen the public education system.
- **Environmental monitoring and protection**. AI can be used to monitor and plan scenarios for climate change and its impact, pollution tracking, wildlife conservation, and natural disaster management. Australia and Netherlands have used such systems successfully.
- **Taxation and revenue management**. AI can be used detect frauds, automate filing and processes, forecast revenues, and improve compliance monitoring. Estonia has developed and deployed a similar system that reduced tax fraud by up to 50%.
- **Access to government programs and services**. AI can be used to simplify access to information about as well as availing government programs and services. It can also improve fraud detection as well as M&E of these programs, resulting in refinements that improve the value delivered to citizens.

Key risks to be mitigated

Not exhaustive

Timeline for Action — Long-term Future | Mid-term Future | Short term Future | Now

Risk Theme	Details	Timeline for Action
Talent and job displacement	• AI can automate many tasks currently performed by humans, potentially leading to job losses. 83% of Indian businesses[1] predict that AI will replace jobs and functions expected to be most impacted by AI include marketing finance and operations. While new job roles will emerge, the scale of transition is likely to require a coordinated response • BPO, KPO and other services sector can witness a decline in demand for new jobs in India due to AI adoption. It would impact routine roles like data analyst, customer service representatives, financial analysts, telemarketers, etc.	
Social, ethical and environmental risks	• **Manipulation with deepfakes and synthetic media:** GenAI can be used to create convincing but fake audio, video, and text content, which can be used to spread misinformation, manipulate public opinion, or damage reputations, create social unrest and erode public trust in media and government. This poses a significant risk for public discourse and democratic processes. • **Bias and discrimination -** AI systems can perpetuate existing biases present in training data, leading to discriminatory practices in areas such as hiring, lending, credit scoring, and law enforcement. This could exacerbate social inequalities and undermine trust in institutions. • **High AI carbon footprint and energy consumption** - Training AI models like GPT-3 produces around 8.4 tonnes[2] of CO_2 annually, contributing to rising emissions with increased AI adoption. India's data centers, using 2%[3] of national power and relying heavily on fossil fuels, further amplify the environmental impact with a significant carbon footprint.	
Cyber and national security risks with malicious use	• **Cyberattacks and data breaches**: AI can be used to automate and enhance cyberattacks, making them more sophisticated and difficult to defend against, e.g., AI-powered malware could be used to target critical infra or steal sensitive data from govt or private companies. • **AI enabled warfare:** Stems from the potential for misidentification of targets, which can result in civilian casualties, and the vulnerability to cyber threats, where adversaries might exploit AI systems, compromising military effectiveness (e.g., manipulating defense systems).	
Erosion of privacy and data security	• **AI systems often rely on vast amounts of data, raising concerns about privacy and data security,** e.g., increased use of facial recognition technology and AI-powered surveillance systems could lead to erosion of privacy and potential misuse of personal data.	

1. The British Standards Institute (BSI) report 2024, 2.Google Estimate, 3. Web Article - Express Computers

Global investment and innovation dashboard (not exhaustive)

Movement in innovation and investment of major economies- 2019-2023

Investment[1]

$ Bn of investments (corporate plus startups) related with AI and Generative AI related keywords

	2019	2023		
Region	**Equity**	**Equity**	**% change**	**Government spending on AI**
US	333	341	2%	$ 1.9 Bn in 2019 and $ 3.3 Bn in 2023 on AI/ML non-defense sectors and $ 4 bn in 2023 on defense[3]
China	18	20	11%	Invested ~ $184 Bn through various state-directed capital funds and subsidies between 2000 and 2023[4]
India	5.6	2.7	- 52%	~$ 1.2 Bn as part of IndiaAI mission in 2024[5]
UK	11.3	11	- 4%	~ $ 0.4 Bn in 2019 for AI initiatives, in 2023 committed $ 1.6 Bn investment (shelved in 2024)[6]
Germany	3.1	2.7	-13%	$ 5 Bn investment for 2019-2025, with $ 500 Mn allocated in 2019[7].
France	1.5	3.6	140%	~$1.5 Bn funding for AI Strategy as part of 2030 plan[8]

Innovation[2]

# of research publication with AI and Generative AI related keywords

Region	2019	2023	% change
US	37,741	57,194	52%
China	29,935	91,219	205%
India	7,074	22,232	214%
UK	9,773	17,743	82%
Germany	7,934	14,056	77%
France	4,100	6,709	64%

Key takeaways

Investment

- U.S. leads in global investment consistently between 2019-2023.
- China though second in private investment, has heavy state-funding in AI
- Investment levels in the U.K., India, and Germany have declined.
- Decline in equity funding may be related to changes in strategies during COVID years, resulting in focus on existing portfolio companies

Innovation

- China outpaced other nations in innovation capabilities, with US at a second position.
- Increased activity in other countries too, with 3x increase in India.

1. Investment is sum of capital invested across regions and years between 2019-2023; Equity includes: Public Investments, All Buyout Types; Other Private Equity Types; All VC Stages; All Round Numbers; All Series; M&A/Control Transactions; Non-Control Transactions; Other M&A Transactions; **Does not include government funding. (Source- PitchBook)**
2. Innovation is number of research publications (including non-peer reviewed) between 2019-2023 across regions (Souce- Lens.org)

3. Stanford University, 2024 AI Index Report, 4. National Bureau of Economic Research, 5. PIB, 6. The Guardian 7. OECD, 8. Knowledge4policy

Global Implementation Dashboard: the framework

Ingredients		Description
Direction	**National strategy**	The strategy across the technology's development value chain, key sectors, value at stake, plan for success, and timelines. Funding allocated to strategy (either directly or by fostering investment)
Inputs	**Capital investment**	Investments committed from private and public funds for development of technology across organizations, start-ups, academia to boost infrastructure, product development, and research and development initiatives, etc.
	Talent	Efforts to build skilled workforce, through talent attraction (sponsorship, awareness), education infrastructure build (courses, schools, tools, investment), and fostering industry linkages
	Infrastructure	Establishment of required infrastructure (technology parks, data centers, compute power, etc.)
	Data	Efforts and guidelines to manage, collate data and establish access for research and commercialization
	Technology	Efforts to promote development and access of underlying tech. (indigenous developments, IP restriction, etc.)
	Risk management	Establishment of policies that accelerate innovation and commercialization while appropriately managing risk (privacy, safety, security).
Execution	**Adoption**	Enablement of at-scale application through strategic positioning, market access, demand creation, along with incentives (tax breaks, subsidies)
	Innovation	Activation of R&D through building Innovation ecosystem, building global partnerships, etc.
	Impact assessment	Measure taken to assess the impact of AI policies and frameworks

Global Implementation Dashboard (1 of 4)

Examples of key initiatives by India and other countries. Not exhaustive.

		India	Other countries
Direction	**National strategy**	• **India AI Mission 2024 with a budget allocation of $1.2 Bn[1]** aims to create an ecosystem for artificial intelligence innovation in India by enhancing accessibility, promoting ethical practices, and driving socio-economic growth through indigenous AI development. • **National strategy for AI** to **promote AI for all**, with focus sectors – Healthcare, Agriculture, Education, Smart cities, Mobility.	• **USA: National Artificial Intelligence Research and Development Strategic Plan 2023** emphasizes maintaining U.S. leadership in AI through responsible research and development, ethical standards, and public-private partnerships. • **China:** AI is **integrated into broader national strategies** ("Made in China 2025" and 14th Five-Year Plan), ensuring AI development is aligned with economic and industrial goals.
Inputs	**Capital investment**	• **Budgetary allocation of $1.2 Bn[1]** for AI **Mission 2024**. • AI startup investments stood at $1.39 Bn in 2023 **and $9.9 Bn between 2013-23[3]**. Indian AI market is expected to **attract investments of $ 4 Bn by 2027[2]**.	• **USA:** AI startup investments **~ $67 Bn in AI in 2023 and $335.24 between 2013-23**; **Federal government** spending on AI/ML **hit $3.3 Bn[3] IN 2023**. • **China:** Invested **~ $184 Bn[4] through various state-directed capital funds and subsidies** between 2000 and 2023; AI **start-up investment in AI** was at ~ $7.8 Bn[3] in 2023; $**103.65 Bn b/w 2013-23[3]**.
	Talent	• Current **AI skills gap in India stands at 51%,** with higher demand-supply disparity (60-73%)[5] for roles such as ML engineers, data scientists, etc. • **Indian AI talent pool** is expected to become **3rd largest** base from 600–650k to over 1.25 Mn over 2022-27[2]. However, major share of it moves abroad for higher pay and innovation opportunities. • **IndiaAI Future Skills (under India AI mission)** can mitigate barriers to entry into AI programs and increase AI courses in undergraduate and higher education Data and AI Labs will be set-up to impart foundational level course.	• **USA**: DOE is leveraging its network of national laboratories to train **500 new researchers by 2025[6]** to meet demand for AI talent ; NSF investing **~ $8M in EducateAI[7]** awards to develop next generation of well-trained AI workforce. • **Singapore**: The National AI Strategy 2.0, 2023 aims to **boost AI practitioner pool to 15,000 in the next 5 years**; **SGD 7 Mn invested into a new AI Accelerated Masters Program** in collaboration with local universities[8].

1. Government of India Press Release
2. S&P Global, NASSCOM and Deloitte India Report
3. Stanford University, 2024 AI Index Report
4. National Bureau of Economic Research
5. Nasscom Report - State of Data Science & AI Skills in India
6. The White House Statement
7. US National Science Foundation
8. Smart Nation Singapore , NAIS 2.0

Global Implementation Dashboard (2 of 4)

Examples of key initiatives by India and other countries. Not exhaustive.

		India	Other countries
Inputs	**Infrastructure**	• India has 6 high performance computers (out of top 500)[1]. It targets is to establish **~10,000 GPUs**[2] **worth of AI compute capacity**. • Operational data center capacity is 1.4 gigawatts (GW) [3]	• **USA** has 173 high performance computers (out of top 500)[1]. Leads with major share of the global GPU market, driven by companies like NVIDIA and AMD Currently has **13 GW**[3] **of operational data center capacity across 10 markets.** • **China** has 63 high performance computers (out of top 500)[1]. Mainland China retains largest data center operational capacity in Asia Pacific at 4.2 GW[3]**;** Has invested ~ **$6.1Bn**[4] **in eight major data center hubs** in the past years
	Data	• **IndiaAI Datasets Platform** launch **aims to** revolutionize access to non-personal data, empowering Indian startups and researchers to drive AI breakthroughs. It will streamline access to high-quality AI-ready datasets by building a unified platform[5].	• **USA:** Has a **National Data platform**, an extensible data ecosystem to promote innovation • **China**: Has **national data sharing platforms** e.g., National GeneBank Database, The National Basic Science Data Center, etc.
	Technology	• **IndiaAI Innovation** Centre setup, dedicated to developing and deploying indigenous LMMs and domain-specific foundational models in critical sectors. [5] • **BharatGen Initiative** focuses on creating multimodal large language models (LLMs), designed to revolutionize public service delivery and boost citizen engagement. [5]	• **United States**: Leads LLM development, with being home ground for companies like **OpenAI, Google, and Meta**. • **China**: Major tech companies like **Baidu, Tencent, Alibaba, and Huawei** are developing indigenous LLMs. China has implemented regulations requiring approval for LLMs before public release thereby encouraging domestic companies to develop their own models to reduce reliance on foreign technologies;
	Risk management	• India plans to release the draft AI framework. It will include regulations on **high-risk areas** such as deepfakes and will aim to create a balanced approach that **encourages innovation and addresses safety concerns.**	• **EU**: Leads with first **AI law** aimed at ethics, transparency, and human-centric AI **in Artificial Intelligence (AI) Act 2024** • **USA**: **Executive Order on Safe, Secure, and Trustworthy AI 2023** directs federal agencies to implement measures for the safe and secure development of AI to protect human rights, civil liberties, and privacy

1. Top500, November 2024
2. Government of India press release
3. Cushman and Wakefield, H1 2024
4. China's National Data Bureau
5. IndiaAI

Global Implementation Dashboard (3 of 4)

Examples of key initiatives by India and other countries. Not Exhaustive.

		India	Other countries
Execution	**Adoption**	• **IndiaAI Startup Financing** (under IndiaAI Mission) approved government financing for deep tech startup ecosystem, with **$ 240 Mn** allocated. • Indian Government has announced a viability **gap funding model** which will **subsidize compute costs by up to 50% for startups** utilizing GPUs to lower the financial barriers for businesses[1]	• **USA:** Federal R&D tax credits can offset up to **22% of qualifying expenses related to AI development[2].** New Jersey enacted a program (2024) that offers up to **$250 Mn in tax credits for firms that derive more than half of their revenue from AI development or employ +50% of their staff in this field[3].** • **Singapore:** Launched **Generative AI x Digital Leaders Initiative** to provide businesses with access to GenAI expertise and resources; An investment of **+ $20 Mn[4]** in the next three years to increase the number of **SG Digital Scholarships and overseas internships in AI roles**
	Innovation	• **Output: 14k[5] average annual research publications** on AI between 2019-23 and only 1,350 GenAI patents from 2014-23, ranking fifth after China, US, Republic of Korea and Japan[6]. • Infra- **3 AI CoEs, focused on healthcare, agriculture, and sustainable cities**, established to spearhead cutting-edge research and practical AI applications. [9] • **Global partnerships**: Solidifying role in AI innovation by hosting **Global AI Summit** (2024) and serving as **chair of the Global Partnership on Artificial Intelligence (GPAI)** – 29-member country group. Advanced AI impact with joint grants such as $ 2Mn+ for AI and Quantum Research with U.S.	• **USA**: ~51k[5] average annual research publications in AI between 2019-23 and 6,300 patents filed since 2014 for Gen AI[6]. In 2023, **61 notable AI models originated from U.S.-based institutions**, far outpacing the European Union's 21 and China's 15[7]. Infra- Established **two new National AI Research Institutes for building AI tools**. Launched **National AI Research Resource (NAIRR**) pilot and awarded over 150 research teams' access to computational and other AI resources. • **China:** ~60k[5] average annual publications between 2019-23; Holds 70% of the Gen AI patents (~38k) filed globally between 2014-24[6]. Established research and innovation hubs, e.g., Beijing Artificial Intelligence Standardization Research Institute. **UK and US are its top two research partners for AI.** It aims to become the world's major AI innovation center by 2030, with the scale of its AI core industry exceeding $ 140 Bn[8].

1. Government of India press release, Meity
2. US Federal Government
3. Reuters
4. Smart Nation Singapore
5. Lens.Org
6. World Intellectual Property Organisation
7. AI Index Report 2024 , Time period for patents 2010-22
8. State Council of People Republic of China
9. IndiaAI

Global Implementation Dashboard (4 of 4)

Examples of key initiatives by India and other countries

		India	Other countries
Execution	**Impact Assessment**	• **No formal mechanisms for comprehensive impact assessment;** Limited **structured frameworks** comparable to global leaders	• **United States**: The Center for Data Innovation published an **AI Policy Report Card** that evaluated the effectiveness of U.S. AI policies across various dimensions e.g., innovation and regulatory frameworks. The Federal government maintains **inventories of AI use cases** across its agencies which **help track how AI is being utilized** to enhance public services and ensure that implementations align with ethical standards. These Federal agencies (NSF, DOD, etc.) are also expected to provide **detailed accounting of their AI activities in response to AI memorandums**, which assess how well the AI policies are functioning. • **France**: Appointed Clara Chappaz, as the country's first-ever **AI Minister** who will be responsible for the oversight of national AI initiatives, to foster innovation and ethical governance.

Opportunities for India to Lead in AI (1 of 2)

As the global race to harness the transformative potential of Artificial Intelligence (AI) accelerates, India is uniquely positioned to emerge as a leader in this domain. With a robust technological ecosystem, a large pool of skilled talent, and a commitment to inclusive development, India can leverage AI to drive sustainable growth and global leadership. Below are some key opportunities for India to lead in AI:

1. Human-Centric AI Development: India's development model, rooted in inclusion and human-centricity, offers a strong foundation to lead in building AI solutions that address real-world challenges. By focusing on AI applications in critical sectors like healthcare, agriculture, and education, India can create scalable and impactful solutions tailored to diverse populations. Innovations like predictive health analytics, personalized learning systems, and precision agriculture can significantly enhance quality of life while ensuring equity.

2. Renewable Energy for AI: The growing energy demands of AI systems necessitate sustainable solutions. India’s leadership in renewable energy, particularly in solar and wind power, positions it as an ideal hub for energy-efficient AI development and operations. By integrating renewable energy into AI infrastructure, India can not only reduce its carbon footprint but also attract global investments in green data centers and energy-optimized AI research facilities.

3. Becoming a Global Talent Hub: India boasts one of the world’s largest pools of STEM graduates and experienced professionals, making it a natural hub for AI talent. With a focused effort to upskill the workforce through initiatives like AI skilling programs and partnerships with academia, India can become the preferred destination for global AI talent. Establishing centers of excellence in AI and fostering collaborations between industry and academia will further strengthen India’s position.

4. Balanced and Forward-Looking Regulation: India’s regulatory approach to AI must balance innovation with ethical considerations. A robust, transparent framework that addresses data privacy, algorithmic accountability, and bias mitigation will ensure trust in AI systems. By adopting a human-first regulatory stance, India can set global standards for responsible AI, attracting innovators who seek a stable and supportive policy environment.

Opportunities for India to Lead in AI (2 of 2)

5. AI for Social and Economic Transformation: India's vast and diverse population presents an unparalleled opportunity to develop AI solutions that drive large-scale social impact. AI can enhance governance through improved decision-making, streamline public service delivery, and optimize infrastructure management. These applications not only benefit India but also create exportable AI models for other developing nations, reinforcing India's position as a global AI leader.

6. Strategic Investments in AI R&D: India needs to increase its investments in AI research and development (R&D) to foster innovation and intellectual property creation. Establishing world-class R&D hubs, incentivizing startups, and nurturing an entrepreneurial ecosystem will drive breakthroughs in AI technologies. Special focus on areas like artificial general intelligence (AGI) and sustainable AI can position India at the forefront of frontier research.

Conclusion:

By capitalizing on these opportunities, India can establish itself as a global leader in AI while addressing its national priorities of inclusive growth and sustainability. With the right investments, strategic vision, and collaborative efforts between the government, industry, and academia, India can truly shape the future of AI for the benefit of humanity. This vision aligns with India's aspiration to become a developed nation by 2047, proving that AI is not just a tool for progress but a key enabler of a more equitable and prosperous world.

Future Front: Quarterly Frontier Tech Insight

Bioengineering

Dec 2024

Bio-engineering: What is it and why does it matter?

What is it?

Bioengineering[1] applies engineering principles to biology to build solutions across domains, and is integral part of bioeconomy, driving economic growth and innovation, employment and environment sustainability.

- **Gene editing:** DNA modification of organisms using advanced tools (e.g., CRISPR) to cure diseases or introduce beneficial genetic traits
- **Tissue engineering:** Creation of artificial functional tissues and organs in a lab by combining cells with biocompatible materials (e.g., metals for orthopedic implants, plant-derived collagen for lab-grown meat). This enables more effective regenerative medicine, organ transplantation, and sustainable food production
- **Biomaterials / Bio-replacements** are substances derived from biological sources (e.g., bioplastics from corn starch) or engineered to interact with living systems. These materials are tailored to create sustainable and eco-friendly alternatives to conventional materials

Why does it matter?

Bioengineering can generate significant economic impact (as key driver of GDP) **through:**

- **Revolutionizing healthcare:** Enhanced disease diagnostics and targeted treatments through gene editing and tissue engineering. Whilst biomanufacturing helps to optimize production cost of essential medicines like insulin
- **Transforming food security and agriculture:** Development of new crops and bio-based agricultural products, enabling sustainable agriculture through efficient land use, reduced need for chemicals, enhanced nutritional content, and minimal environmental impact
- **Building sustainable alternatives with improved performance:** Develop materials with unique traits or produce through eco-friendly mechanisms (e.g., bioplastics and biofuels) to reduce environmental impact and enable sustainable resource management
- **Enabling environmental restoration:** Leverage biomaterials to clean contaminated resources (e.g., water, soil, air), and contribute to carbon capture, mitigating climate change and ecosystem restoration.

Key associated risks-

- **Bio-warfare risk:** Bioengineering allows for easier creation/ modification of dangerous pathogens, potentially leading to novel bio-weapons that can be difficult to detect and defend against. It poses a risk of uncontrollable outbreaks with potentially devastating consequences.
- **Ethical risk** including public skepticism about its safety, the potential for exacerbating inequalities, and the concentration of power/ access needs ethical considerations by ensuring transparency, rigorous safety assessment and equitable access.

1. Focus on bioengineering as a technology trend, related opportunity and risks and not bioeconomy as a whole

Examples of Global applications

Not exhaustive

Archetype	Description	Examples of Global Use Cases	
Revolutionizing Healthcare	• Conduct gene testing, sequencing and editing to aid early detection and development of novel treatments • Manipulate genes / enzymes to increase yield and reduce cost of medicines	**Diagnostics**: Early & accurate diagnosis for diseases such as cancer **Treatment:** Personalized treatment (e.g., CAR-T high remission treatment of cancer), CRISPR based treatment of diseases like sickle cell **Efficient medicine production:** Example- Modifying the bacteria's metabolic pathway for higher yield (can be more than 2x) of medicines (e.g., insulin)	**Galleri** **Novartis** **Biocon**
Transforming Food Security and Agriculture	• Develop genetically edited or modified crops with desirable traits (e.g., drought and pest resistance) • Develop meats or fortified foods in labs in controlled and precise manners	**Agriculture:** GMO crops (e.g., drought resistant maize) with higher pest and drought resistance, improving yield by 20-50% and using 50-60% lower pesticides. Thereby increasing food security and reducing cost **Food:** Functional**,** nutrition fortified foods, e.g., iron and vitamin fortified beans, and smart proteins to address deficiency, improve health health, with low carbon footprint produced using tools like synthetic biology	**Bayer Crop Science** **EatJust** **HarvestPlus**
Building Sustainable Alternatives	• Develop sustainable alternatives such as biofuels, from renewable biological sources of maize, algae, etc., and bioplastics, derived from corn starch, sugarcane, etc.	**Packaging:** Methods such as AuraPHA's development of PHA based single-use biodegradable plastics to replace conventional plastic **Consumer goods:** Sustainable biobased nylon vs petroleum-based nylon, reducing reliance on fossil fuels and greenhouse gas emissions	**Genomatica**
Ensuring Environmental Restoration	Restore ecosystems, combat climate change, through: • **Bioremediation** using microorganisms to break down pollutants in soil and water • **Carbon capture** with genetically engineered plants / algae that absorb more CO2	**Wastewater treatment:** Dissolving organic matter and municipal waste into simpler molecules, helping recycle the waste-water **Industrial utilities:** Capture ~90% of CO2 released by industrial utilities (e.g., cement plants[3]) and utilize it for other industrial processes (e.g., oil recovery)	**Thermax, Ecolab** **Carbon Clean**

1. Qaim and Zilberman (2003) – "Yield Effects of Genetically Modified Crops in Developing Countries",
2. Bennett, R (2006) - "Farm-level economic performance of genetically modified cotton", 3. https://www.carbonclean.com/en/press-releases/c1-launch

Risk Mitigation is key for Success (1 of 2)

Bioengineering presents a range of key risks that can be classified into several categories. Understanding these risks is crucial for developing effective management strategies and ensuring the responsible advancement of the field. The primary classifications of risks in bioengineering include:

- Safety Risks:
  - Participant Safety: In biomedical applications, the safety of individuals involved in clinical trials or treatments is paramount. Risks include adverse reactions to genetically engineered therapies.
  - Biosafety Risks: These refer to the potential for engineered organisms to inadvertently escape controlled environments, leading to unintended consequences for human health and the environment. This includes the risk of creating more virulent pathogens or harmful biochemicals
- Ethical and Social Risks:
  - Ethical Dilemmas: Technologies such as genome editing raise significant ethical questions, particularly regarding equity and access. There are concerns about creating disparities between those who can afford genetic enhancements and those who cannot
  - Public Perception and Acceptance: Widespread skepticism about the safety and long-term effects of bioengineering can lead to public resistance, which may hinder research and application efforts
- Environmental Risks:
  - Ecosystem Disruption: The introduction of bioengineered organisms can disrupt local ecosystems, leading to issues such as cross-contamination with wild species and the emergence of herbicide-resistant superweeds
  - Loss of Biodiversity: Over-reliance on genetically modified crops may threaten traditional agricultural practices and diminish genetic diversity within crops, which is vital for food security

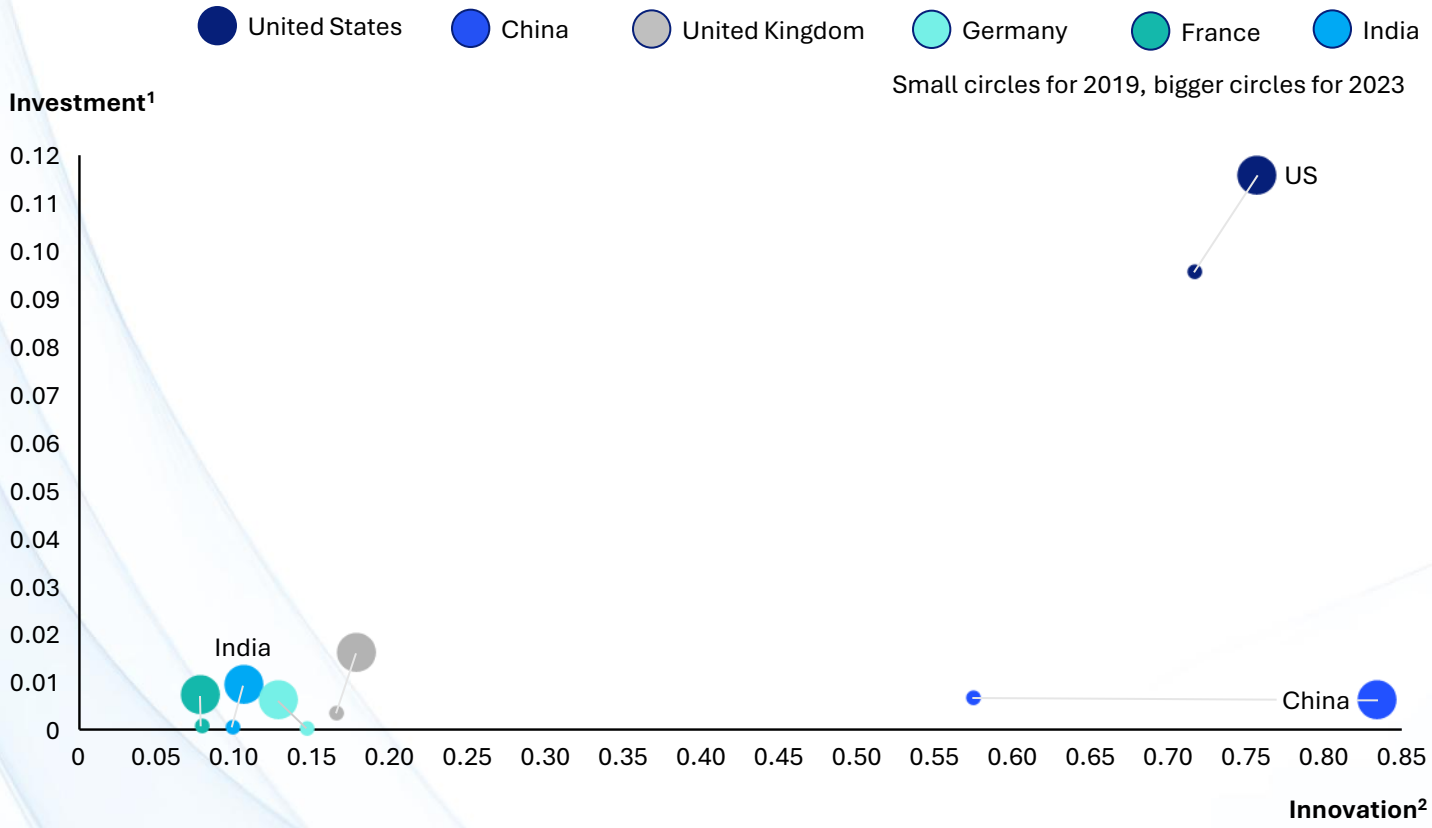
Risk Mitigation is key for Success (2 of 2)

- Biosecurity Threats:
  - Dual-Use Risks: Certain bioengineering technologies could be misused for harmful purposes, such as bioweapons development. For example, engineered pathogens could be weaponized or used in biological attacks
  - Accidental Releases: The unintentional release of engineered pathogens poses serious risks to public health and safety, as evidenced by historical incidents involving laboratory accidents
- Economic and Strategic Risks:
  - Market Disruption: The rise of community bio-labs and open-source technologies may disrupt traditional pharmaceutical markets, leading to quality control issues and potential misuse of therapies
  - Dependence on Foreign Technologies: Insufficient investment in domestic bioengineering capabilities could result in reliance on foreign innovations, affecting national security and economic stability

Addressing these risks requires a multifaceted approach that includes robust regulatory frameworks, ethical governance, public engagement, and ongoing research into the implications of bioengineering advancements. By proactively identifying and managing these risks, stakeholders can foster innovation while safeguarding public health and environmental integrity.

Global investment and innovation dashboard (not exhaustive)

Movement in innovation and investment of major economies- 2019-2023



Investment here focuses on private and public equity investments, and doesn't include government/ state-funding

1. Investment score is sum of capital invested normalized to scale of 1 across regions and years between 2019-2023; Deal Types: Public Investments, All Buyout Types; Other Private Equity Types; All VC Stages; All Round Numbers; All Series; M&A/Control Transactions; Non-Control Transactions; Other M&A Transactions;
2. Innovation score is number of research publications (including non-peer reviewed) normalized to scale of 1 between 2019-2023 across regions

Source: Investment- Pitchbook, Innovation- Lens.org

Key takeaways

Innovation:

- China leads innovation in 2023 whereas the USA led innovation in 2019
- No significant shifts in innovation for other nations in the last 5 years

Investment:

- The US leads investment across 2019-2023 by a significant margin vs. other economies
- China has seen a drop in investment between 2019-2023, whereas other nations saw growth in investments
- India has seen an increase investments from government and private sector. However, total investments are very low relative to other nations

Framework for Global Implementation Dashboard

Ingredients		Description
Direction	**National strategy**	The strategy across the technology's development value chain, key sectors, value at stake, plan for success, and timelines. Funding allocated to strategy (either directly or by fostering investment)
Inputs	**Capital investment**	Investments committed from private and public funds for development of technology across organizations, start-ups, academia to boost infrastructure, product development, and research and development initiatives, etc.
	Talent	Efforts to build skilled workforce, through talent attraction (sponsorship, awareness), education infrastructure build (courses, schools, tools, investment), and fostering industry linkages
	Infrastructure	Establishment of required infrastructure (technology parks, data centers, compute power, etc.)
	Data	Efforts and guidelines to manage, collate data and establish access for research and commercialization
	Technology	Efforts to promote development and access of underlying tech. (indigenous developments, IP restriction, etc.)
	Risk management	Establishment of policies that accelerate innovation and commercialization while appropriately managing risk (privacy, safety, security).
Execution	**Adoption**	Enablement of at-scale application through strategic positioning, market access, demand creation, along with incentives (tax breaks, subsidies)
	Innovation	Activation of R&D through building Innovation ecosystem, building global partnerships, etc.
	Impact assessment	Measure taken to assess the impact of AI policies and frameworks

Global Implementation Dashboard (1 of 3)

Examples of key initiatives by India and other countries. Not Exhaustive.

Not exhaustive

		Examples of Initiatives taken by India	Global Examples
Direction	**National strategy**	**BioE3 policy (2024) to** create a **biomanufacturing eco-system** to boost economy, employment and environment, with focus to- i) intensify research to address challenges like climate change, ii) support innovation, incl. synthetic biology, metabolic engg., iii) progress in 6 strategic sectors- bio-based chemicals, smart/ functional foods, precision biotherapeutics, resilient agriculture, carbon capture and its utilization, marine and space research. **National Biotechnology Development Strategy** 2020-25 aims to make India globally competitive in **research, innovation, entrepreneurship and industrial growth.**	• **USA:** National strategy 2022 **coordinates R&D, biological data ecosystem, biomanufacturing, biomass production**, market opportunities, workforce, regulations, and risk mgmt. to advance biotech. Key sectors incl. healthcare, agriculture, energy, climate change, supply chain resilience, national security • **Germany:** National Bioeconomy Strategy 2030 focuses on **transitioning to sustainable, resource-efficient economy** through bioeconomy solutions, sustainable / renewable materials, and innovation and knowledge creation
Inputs	**Talent**	**India has a shortage of research talent. Also, this talent is at risk of brain drain to developed markets.** **1Mn+ skilled** biotech workforce **260 researchers** in R&D per million people (2020[1]) **34% STEM graduates** as share of tertiary education (2022) **1,400+ institutions** offer biotech courses	• **USA:** 1.5Mn+ skilled biotech workforce. **4,452 researchers** in R&D per million people (2020[1]). **20% STEM** graduates as share of tertiary education (2022). **>200 institutions** offer biotech courses, with world-renowned institutions like MIT, Stanford, and Harvard attracting and producing top talent • **China: 4 Mn+ biotech skilled workforce. 1,602 researchers** in R&D per million people (2020[1]). **41% STEM graduates** as share of tertiary education (2020[2]). **>360** institutions offer biotech courses. Scholarships are offered for STEM PHDs abroad with condition to return
	Capital investment	Low VC investment was **$0.9 Bn in 2022,** and limited R&D investment at **$1 Bn in 2022** (0.03% of GDP- **lower than many developed and other BRICS countries**) **–** DBT utilized only ~72% of allocated funds. Private sector participation encouraged through initiatives like Biotechnology Industry Partnership Program (BIPP), focused on 7 themes; ~$65 Mn committed by the govt. for 300+ beneficiaries by 2023.	• **USA:** VC investment in biotech and pharma was **$70 Bn in 2021-22**. **Govt allocated $45 Bn to R&D 2022** (0.2% of GDP), through NIH budget.. Well-developed PE/VC market that consistently invests in biotech startups • **China:** VC and private equity investment was **$28 Bn between 2021-22**. **Govt allocated $30 Bn to R&D** (0.2% of GDP) in 2022 through ministry budgets. The sector is supported by robust private investment landscape, public markets like the Hong Kong Stock Exchange, and adoption of ICH guidelines that provide credibility for global investors

1. Latest comparable data is available for 2020; 2. Latest graduate data for China is only available for 2020

Source: National Biotechnology Development Strategy 2020-25; India Bioeconomy report, 2024 (BIRAC), How Innovative Is China in Biotechnology (ITIF), Trading Economics- World Bank Collection, World Economic Forum, CollegeDunia

Global Implementation Dashboard (2 of 3)

Examples of key initiatives by India and other countries. Not Exhaustive.

Not exhaustive

		Examples of Initiatives taken by India	Global Examples
Inputs	**Infra-structure**	**~10 bio-parks** span pharmaceuticals, bioinformatics, and agricultural innovation sectors for commercialization & research; **19 registered biobanks** out of 340 globally, developing but smaller-scale biobank infrastructure compared to global leaders.	• **USA: >10 biotech hubs,** and NIH's research facilities provide advanced infrastructure for biotech R&D and commercialization • **Germany** hosts 30+ biotech parks,13 lifescience clusters and **German Biobank Alliance** integrating 30 biobanks for facilitating research.
	Data	**Repositories**: Indian Biobank Data Consortium (IBDC) and Ayushman Bharat digital platform offer integrated healthcare data under 2022 National Guidelines for Biobank Establishment, but interoperability challenges persist;	• **USA:** NIH's *GenBank* and *PubMed* databases provide extensive biomedical data access, supported by a *Genomic Data Sharing Policy* ensuring secure, consent-driven data use. *The All of Us Research Program*: 1Mn+ genomes linked with health records.
		Genome India Project: developing initiative to consolidate genomic data, though integration with clinical datasets is currently limited.	• **UK:** *UK Biobank* has sequenced 2L+ genomes, targeting 5L+ by 2025; *Our Future Health* aims for 5 Mn+ participants, supporting advanced polygenic risk and healthcare studies.
	Technology	**Technological Accessibility:** Genome sequencing and sensor technologies have become more affordable, enhancing access but lagging in broad adoption across clinical and research. NBDS 2021-25 to strengthen capacities in bioinformatics, synthetic biology, and quantum biology **Digital Health Platform:** Ayushman Bharat integrates clinical data from healthcare providers but requires further technological maturity for large-scale genomic integration	• **USA:** Advanced in CRISPR-Cas systems, with high-fidelity variants critical for therapeutic uses. Leads in synthetic biology innovations, e.g., **3D bioprinting** for regenerative medicine and microbiome-based therapies. • **Japan: 7 biotech parks** as hubs for R&D and commercialization. Focus on medicine, pharmaceuticals, advanced medical devices; Notable for integrating with robotics and AI. **MID-NET Database combines medical records** to enable drug safety and research
	Risk and regulations	Biotechnology Regulatory Authority of India Act (2016) **provides** framework **for safe use of biotech** DBT **updated Biosafety Regulations,** for emerging tech, biosafety, risk assessment, and public engagement. BIRAC-PATH set-up to support innovation amongst biotech startups and SMEs with IP and tech transfers. DBT introduced new IP guidelines to improve the commercialization of public-funded research (flexible licensing, protection mechanisms)	• **USA: Stringent IP laws** protect biotech innovations, and agencies like FDA and EPA provide **faster and clearer processes for approval** of biotech products, e.g., approvals for new drugs takes 12 months for standard process and 6 months for priority • **EU:** 1st region to define policy framework for **approval of biosimilars**. Biotechnology and Biomanufacturing Initiative simplifies regulation and speeds up approvals. • **China:** NMPA piloted optimized approval of overseas/ innovative drugs to ~30 days with initiatives, e.g., clinical trial waivers, reduced inspection timelines

1. Latest comparable data is available for 2020; ; 2. Latest graduate data for China is only available for 2020

Source: National Biotechnology Development Strategy 2020-25; India Bioeconomy report, 2024 (BIRAC); How Innovative Is China in Biotechnology (ITIF); IP India; National Science board

Global Implementation Dashboard (3 of 3)

Examples of key initiatives by India and other countries. Not Exhaustive.

Not exhaustive

		Examples of Initiatives taken by India	Global Examples
Enabling output	**R&D**	**900 biotechnology patents** obtained in 2023. **43 H-Index[1]** score for scientific publications in biological manufacturing in 2023 16 biotech focused institutions for research, 200 bio-incubators BIRAC has **100+ national and international partnerships**, 9 new partnerships with global biotech organizations (Danaher) R&D support initiatives incl. Biotechnology Ignition Grant (BIG) with $ 60 Mn funds committed, 500+ IPs and 125+ products supported;	• **USA: 14% of global** scientific & engineering publications in 2022. **3.7K biotechnology patents** obtained in 2023. **60 H-Index[1]** score for scientific publications in biological mfg. in 2023. **~40% of global drug** originate in US. Working groups for public-private collaborations and multi-lateral dialogs (Biopharma Coalition- Bio-5, U.S.-EU partnership). • **China: 27% of global publications** in 2022. **1.9K biotechnology patents** obtained in 2023. **61 H-Index[1]** score for scientific publications in biological manufacturing in 2023. **23% of global drug** candidates originate from China. **5+ global forums** on biotech developments. Govt. support incl. subsidies, research grants (National High-tech R&D, National R&D Program), dedicated R&D centers /hubs, e.g., BGI);
	Adoption and scaling	**2 key institutions** in place to support biotech development, **DBT ($1 Bn budget)** and BIRAC**. BIRAC has supported 316 start-ups, which generated $125 Mn funds.** BIRAC set-up the first hub to actively facilitate and provide resolution for startups and innovators Incentives to promote R&D incl. **100% write-off on revenue and capital expenditure on R&D**, weighted tax deduction of 200% for in-house R&D for biotechnology companies Bioeconomy is valued at **$150 Bn in 2023 (4% of GDP)**, with 43% from bio-industrial and 36% from biopharma	• **USA:** Govt support incl. Research & Experimentation Tax Credit (**175% deduction R&D** expenses from their taxable income, 15% reduction in corporate tax), fast track process for addressing unmet medical needs, dedicated PPPs (Biomedical Advanced Research and Development Authority, Advanced Research Projects Agency for Health). Bioeconomy is valued at **$900 Bn in 2023 (5% of GDP)** • **China:** Supported with tax credits (e.g**., 20% tax credit for R&D expenses**), grants, and subsidies (e.g., ~$500k for new mfg. facilities), to encourage innovation. Other efforts incl. streamlining processes and time-to-market for new drugs and medical devices. Bioeconomy is valued at **$800 Bn in 2023 (4% of GDP)**
	Impact assessment	**Indian Bio-Economy Report (IBER)**: Tracks the sector's economic contributions, updating progress towards a USD 150 billion bioeconomy target by 2025. **Department of Biotechnology (DBT) o**versees India's bioengineering landscape with initiatives (e.g., BIRAC)	• **USA: Biotechnology Innovation Organization (BIO)** coordinates policy advocacy, industry benchmarks, and market reports, ensure ongoing assessment of biotech's economic impact • **UK: BioIndustry Association (BIA)** to engage in periodic impact assessments, emphasizing R&D performance, regulatory advancements, and economic metrics to guide industry strategy

1. A metric that measures the productivity and impact of a scientist or scholar's published work

Source: National Biotechnology Development Strategy 2020-25; India Bioeconomy report, 2024 (BIRAC); Information Technology and Innovation Foundation), India brand equity foundation

BioE3 Policy : Ushering in bio-revolution in India

- Keeping in view the national priority of steering Bharat on the path of accelerated ‘Green Growth’, an integrated BioE3 (Biotechnology for Economy, Environment and Employment) Policy for “Fostering High-Performance Biomanufacturing” is proposed for a green, clean, prosperous, and self-reliant Bharat.
- The Policy provides a framework to empower Indian institutions, universities, startups and industries to engage in transformative innovations by:
  - Intensifying research and innovation to address challenges such as mitigation of climate change and achieving de-carbonization
  - Boosting domestic biomanufacturing capability by enabling synergy between science, technology, engineering and manufacturing
  - Accelerating transition to biomanufacturing by promoting integrated use of artificial intelligence (AI) and digitalization with ‘omics’ and upstream biotechnology innovations
  - Setting up the facilities (Biomanufacturing Hubs/ Biofoundry/ Bio-AIs) for scaling-up and pre-commercial manufacturing, co-located with resources and infrastructure for fostering high- performance biomanufacturing
  - Nurturing cohort of highly skilled workforce
- Six thematic sectors of national importance have been prioritized for implementation under the BioE3 Policy. These focus areas include: i) Bio-based chemicals and enzymes, (ii) Functional foods and Smart proteins, (iii) Precision biotherapeutics, (iv) Climate resilient agriculture, (v) Carbon capture and its utilization, (vi) Futuristic marine and space research.
- This Policy will place Bharat to realize the full potential of bioeconomic growth with sustainable resource management with inclusivity.

More details at https://bmi.dbtindia.gov.in/pdf/folder.pdf

Priority areas for India to solve for

Theme	Key Insights
Talent and R&D	• India has 14% points **higher STEM graduate proportion than the US, but it has** lower absolute biotech workforce (~1 Mn in India vs ~4 Mn China in 2020) **far fewer research scientists** (only 10% of US scientists pool). Additionally, R&D output and quality lags behinds leading countries (US and China have 2-4x the number of patents).
	• A **weaker R&D ecosystem constrains India's ability to lead in strategic bioengineering** sectors like climate-resilient crops, biofuels, or advanced materials. Talent and R&D needs to further develop to transition to a co-developer of technology as lack of cross-disciplinary expertise (e.g., in bioinformatics, AI, and nanotechnology) hampers India's ability to innovate in fields like personalized medicine.
Investment	• Bioengineering technologies require **significant up-front capital investment to reach commercialization**. India's VC and private equity **investment in biotechnology is <10% of leading countries** (USA and China). These limitations curtail India's ability to scale innovations. Hence, there's need to bolster its VC/ investment ecosystem with focus on select strategic bets.
Tech & infrastructure	• Limited access to state-of-the-art research facilities and advanced biomanufacturing units constrains development and scaling. • Scope to **expand the size and quality of parks and facilities available** (e.g., US Biotech parks employs ~20-50k people on avg. vs ~100-1,500 people in India), and advanced facilities, e.g., large animal breeding, cold storage, etc. across current 9 biotech parks and develop specialized facilities for providing access for scaled pilot. • **Absence of advanced labs delays India's ability to develop next-gen** solutions, e.g., delay in localizing cancer CAR-T treatment. • India has **limited pilot-scale manufacturing facilities** to test and scale biotech innovations. Countries like the U.S. have advanced facilities for both pilot and large-scale biomanufacturing supported by organizations like NIH and USDA.
Regulations	• India has introduced a bio-regulatory framework and updated safety, and IP polices, however, it needs to frame **policies for new technologies, such as genome edited products** (basis GM crop technologies), synthetic biology, thereby delaying commercialization (BT cotton is the only approved GM crop since 2002). • Given the large no of stakeholders, we will need **processes for effective multi departmental coordination** to avoid delays

Source: CSET Georgetown, WeForum

In conclusion, ideas to consider

1. **Invest in Select Battlegrounds with Inherent Advantages:** Focus investments where India holds inherent advantages, such as cost-efficient talent and large-scale demand, to create scalable, globally relevant solutions. Prioritize sectors like healthcare, agriculture, and biomanufacturing, and explore emerging technologies like synthetic biology.
2. **Healthcare Innovation**: Invest in local therapies like NexCAR19, which offers over 60% savings compared to imported therapies. This can make advanced treatments more accessible and affordable, positioning India as a leader in cost-effective healthcare solutions. **Example**: China's investment in local CAR-T therapies has significantly reduced treatment costs and improved accessibility.
3. **Agricultural Advancements**: Promote the ethical development and adoption of gene-edited crops to increase and secure yields and reduce cost. This can transform India's agricultural landscape, making it more productive and sustainable. **Example:** Brazil's success with GM soybeans has led to increased agricultural output and farmer incomes.
4. **Build Global Partnerships and Foster Foreign Investment:** Forge bilateral research and development agreements with countries excelling in bioengineering to gain expertise and access to advanced technologies. Position India as a hub for the Global South by developing assets and solutions tailored to shared challenges, enhancing reach & soft power.
5. **Global Collaboration**: Establish partnerships with leading global innovators who can benefit from India's talent and cost advantages. For example, collaborating with premier institutions to form centers of excellence in India can drive innovation and commercialization. **Example 1**: South Korea's collaboration with global tech giants has accelerated its advancements in biotechnology. Example 2: China association of enterprises' first global corporate partner- Merck collaborated with Bio-valley to establish talent training programs and jointly leverage R&D capabilities in biotechnology innovation and industrialization. Such partnerships help access international markets and research expertise.
6. **Innovation Fund**: Launch a large innovation fund to attract and incentivize private and foreign investment. Offer tax breaks and match funding to scale startups and foster public-private partnerships and establish grants for pilot-scale bio-engineering projects. Promote investment in building dedicated bio-manufacturing hubs near biotech clusters. **Example**: Israel's Yozma program successfully attracted foreign venture capital by offering tax incentives and government matching funds.

NOTES

NITI Aayog