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Will Boosting Biofoundries Transform India's Biomanufacturing Landscape?

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Biofoundries hold the potential to emerge as the backbone of biomanufacturing and synthetic biology, offering integrated infrastructure to streamline the design, construction, and testing of genetically engineered organisms. Biofoundry is a place where biomanufacturing meets automation. The highly modular structure of a biofoundry helps accelerate the design-build-test-learn (DBTL) workflow to deliver products fast and in a streamlined fashion. Advanced platforms to enable rapid, high-throughput experimentation, and automating processes that were once labour-intensive and time-consuming is a central theme.



India has come up with multiple initiatives to support and set up biofoundries, including the BioE3 (Biotechnology for Economy, Environment and Employment) Policy, the Bio-RIDE scheme, and the Vigyan Dhara scheme. The BioE3 Policy lays out plans for accelerating the transition to biomanufacturing by promoting integrated use of Artificial Intelligence (AI), digitalisation with 'omics', and upstream biotechnology innovations through bio-AI hubs, biofoundries, and biomanufacturing hubs across the country. With the new BioE3 Policy in place, coming years will provide insight into how biofoundries will play a role in boosting innovation, scale-up and commercialisation of bio-based products. In addition, with a Global Biofoundry Alliance now established to coordinate biofoundry activities and innovations worldwide, the question arises: how is India positioned in this rapidly evolving field, and what role do biofoundries play in India's biomanufacturing initiatives? Let's explore.

Why do we need biofoundries?

Biofoundries represent a new paradigm in biotechnology research, focusing on efficiency, scalability, and innovation. At their core, these facilities bring together automation, artificial intelligence, high-throughput screening, and advanced analytics to accelerate biological research and product development. The ability to genetically reprogram organisms for various applications—from producing sustainable biofuels and pharmaceuticals to biodegradable plastics and agricultural enhancements—gives biofoundries a pivotal role in shaping the future of biotech industries. The emergence and evolution of engineering biology, and its potential to address multiple global challenges is associated with the rise of biofoundries.

Biofoundries are changing how laboratories approach engineering biology. For example, synthetic biology combines biological, engineering, and computational principles to create complex biosystems. To do this, scientists relied until recently on bibliographic research and previous knowledge to design and build constructs, essentially one by one. This process is time-consuming and expensive and can be compared with the early mechanical engineering steps where the production chain was almost completely manual.

Biofoundries aim to accelerate academic and translational research, especially in engineering/synthetic biology, by enabling researchers/companies access to automation and high-throughput equipment including process scale-up, computer-aided design software, and other new workflows and tools. Iterative Design-Build-Test-Learn (DBTL) biological engineering cycles allow researchers to test large-scale genetic designs and apply Artificial Intelligence (AI)/Machine Learning (ML) to enhance the design process. Other goals include building a robust engineering/synthetic biology industry and accelerating the commercialisation of engineering/synthetic biology and biomanufacturing process engineering.

Innovation in biomanufacturing, to develop new biologics, vaccines, gene therapies, and diagnostics, is underway across the globe. Biofoundries are proving to be instrumental in revolutionising biotechnology for healthcare, agriculture, and environmental sustainability - from personalised therapies and advanced biologics in healthcare to synthetic fertilisers and sustainable bio-based materials in agriculture.

In terms of throughput, current exemplars, as highlighted in 'Building a global alliance of Biofoundries' published in Nature Communications, 2019, include the Edinburgh Genome Foundry, which for example can process over 2000 DNA assembly reactions per week, twenty times the throughput of a single person without automation. At the University of Illinois at Urbana-

Champaign, iBioFAB can build up to 1000 TALEN constructs per day at <$3 each, 0.3 per cent of what it might otherwise cost. Moreover, iBioFAB can perform multiplex genome-scale engineering of *Saccharomyces cerevisiae* in a fully automated manner, greater than ten times the throughput of a single person without automation. Working with small companies, the London DNA Foundry, Singapore SynCTI Foundry, and US DOE Agile BioFoundry now provide cost-effective access to expensive equipment and the necessary expertise for product prototyping and commercial process validation, which are often required to secure additional capital investment.

India's Growing Biomanufacturing Landscape

India has long been recognised for its strengths in pharmaceutical manufacturing, particularly in the production of generic drugs and vaccines. In recent years, the country has expanded its focus to include biomanufacturing, the large-scale production of biologically derived products. India is also expanding into the cell and gene therapy space. The BioE3 policy also highlights precision biotherapeutics as a thematic area of focus. Government initiatives for biotech infrastructure reflect India's commitment to becoming a global leader in biomanufacturing though biofoundries.

Biofoundries are uniquely positioned to accelerate these efforts, as India seeks to enhance its position in the global biotech supply chain. The automation provided by biofoundries can reduce the time and cost associated with biomanufacturing, giving Indian companies a competitive edge in scaling up production. India's biotechnology ecosystem is growing rapidly, with strong support from both the government and private sectors. The Department of Biotechnology (DBT) has been instrumental in fostering innovation through grants, research centres, and collaborations. Biofoundries would fit naturally into this ecosystem by complementing existing research facilities and biomanufacturing plants.

For India, this level of automation could enhance the efficiency and scalability of biomanufacturing processes. While a relatively unexplored concept in the country yet, how India's promising biotechnology landscape and favourable policy framework can enable growth of advanced biofoundries is yet to be seen.

Dr Pawan K Dhar, Executive Director, CVJ Centre for Synthetic Biology & Biomanufacturing said, "India's rich and diverse bio-economy—focusing on areas like sustainable agriculture, renewable energy, and environmental biotechnology—will fuel the growth of localised biofoundry applications. These applications will address key national and global challenges such as food security, pollution, biomaterials, and efficient bioresource management. What's exciting is that the rise of low-cost, high-throughput screening technologies will make these advancements accessible to smaller institutions and startups. This democratisation of bioengineering resources will spur innovation across sectors, placing India at the cutting edge of bio-based manufacturing on the global stage."

The Government of India has introduced several Production Linked Incentive (PLI) Schemes aimed at enhancing domestic manufacturing and attracting significant investments in the life sciences-related sectors. Additionally, initiatives like 'Make-in-India', the National Biopharma Mission (NBM), as well as new provisions from the Anusandhan National Research Foundation (ANRF), to name a few, are set to boost innovation and technological prowess.

Recent significant developments include the approval of the BioE3 Policy for biomanufacturing and the approval of the BioRIDE scheme. These initiatives highlight establishment of biofoundries, in boosting bio-innovation and high-performance biomanufacturing. By providing a platform for rapid prototyping and scaling biomanufacturing processes, biofoundries can support the growth of Indian biotech startups, enhance the country's production capabilities, and drive innovation in bio-based industries.

Sharing his views **Dr Premnath Venugopalan, Director, Venture Center** said, "I think the Biofoundry facilities and capabilities will be especially important for startups looking at emerging opportunities in biopharma (cell and gene therapies, biosimilars, living therapeutics etc), agriculture and nutrition (agrobiologics, climate resilient agriculture), energy and environment (biorenewable chemicals and fuels, sustainable ingredients), blue economy (marine chemicals and materials, aquaculture etc) and other such areas."

By integrating biofoundries into India's biotechnology infrastructure, the country can accelerate the development of cost-effective, and sustainable solutions for healthcare, agriculture, and environmental challenges.

Dr Dhar further said "The growing availability of funding to establish biofoundry infrastructures in India opens up tremendous possibilities, as the country is on its way to becoming a global leader in biotechnology and biomanufacturing. Over the next 5 to 10 years, we can expect to see a rise in biofoundries that bring together academic research, industry collaboration, and government support. These hubs of innovation will likely focus on automating synthetic biology processes, speeding up the development of new biological systems, and leveraging AI to drive breakthroughs in biomanufacturing using sophisticated

computational models.”

Global scenario : The Global Biofoundry Alliance (GBA)

The Global Biofoundry Alliance (GBA) was formally launched on May 9, 2019 in Kobe, Japan to enable the sharing of experiences and resources and for working together to overcome shared challenges and unmet scientific and engineering needs. The GBA is a community collective of publicly funded Biofoundries across the world. The members of the GBA are a test-bed for new technologies and the development of skills. The advanced infrastructure allows researchers to adopt cutting-edge high-throughput workflows and enable accessibility for startups, SMEs, and academic researchers alike. Signing members of the GBA include research institutions, research funding agencies, or other entities that operate non-commercial biofoundries, as well as other organisations that actively support public-funded biofoundries. The parties have non-overlapping missions with for-profit entities.

The Alliance includes member countries like the USA, Singapore, China, Australia, Canada, Germany, Denmark, Finland, Japan, Mexico, South Korea, and the United Kingdom biofoundry destinations like Edinburgh, London, and Manchester, and India. Out of the prominent member countries of the GBA, India perhaps stands as a relative newcomer, with ‘Biofoundry India’ from Delhi representing the country at the GBA.

The objectives of the GBA include-

1. Develop, promote, and support non-commercial biofoundries established around the world,
2. Intensify collaboration and communication among biofoundries,
3. Collectively develop responses to technological, operational, and other types of common challenges,
4. Enhance visibility, impact, and sustainability of non-commercial biofoundries, and
5. Explore globally relevant and societally impactful grand challenge collaborative projects.

GBA: What It Means for India

The establishment of the GBA marks an important milestone in the coordination of biofoundry activities across the world, promoting collaborations among biofoundries in different countries. For India, participation in this alliance could be beneficial, in terms of an enhanced access to cutting-edge technologies, expertise, and international partnerships. By being a part of the GBA, Indian biofoundries can tap into a global network of innovation, accelerating the country’s ability to meet both domestic and international demands for biotech products. This also could also position India as a strategic player in the global biotech supply chain, especially as the need for sustainable, scalable solutions in healthcare and agriculture continues to grow.

Challenges and way forward

While biofoundries hold incredible promise, academic researchers may face several hurdles in fully tapping into their potential. Researchers coming purely from a biological background adapting to automation and advanced technologies on one end, to managing the massive amounts of data generated by Biofoundries on the other, will find it difficult to work at biofoundries.

Explaining challenges working at biofoundries, Dr Dhar said, “One of the biggest challenges is a mental disengagement with the traditional slow and steady model of performing cellular edits and waiting for the response that can take weeks together. Moving to a biofoundry approach would call for a new way of thinking and designing experiments. In addition, the high cost of establishing biofoundry infrastructure can be difficult for smaller labs with limited budgets. One way to overcome this is through by establishing hub and spoke model across the nation and enhancing collaborative efforts between universities, industries, creation of shared, open-access resources that empower researchers at an affordable cost. For those coming from a purely biological background, adapting to automation, robotics, and AI might feel overwhelming. To bridge this gap, academic institutions will need to invest in cross-disciplinary programmes that teach both technical and computational skills, ensuring researchers are well-equipped to navigate the biofoundry landscape.”

He also added that managing the massive amounts of data generated by biofoundries presents its challenges, in that establishing clear guidelines around data sharing, ownership, and intellectual property will be crucial factors. “By developing transparent frameworks for handling these aspects, researchers can collaborate more freely and make the most of the

breakthroughs biofoundries offer", he said.

Dr Gaurav Singh, CEO of Blockchain for Impact (BFI) highlighted some other challenges that will be encountered in establishing biofoundry infrastructures and promoting the Design-Build-Test-Learn (DBTL) approach in India. He said, "High capital investment in building state-of-the-art biofoundries requires significant upfront capital investment in cutting-edge equipment and technologies like synthetic biology, automated screening, and genetic engineering. In addition, a limited expertise and talent pool, the biotechnology workforce often lacks specialised skills in areas like bioinformatics, AI-based modelling, and advanced bioprocess engineering, which are crucial for DBTL."

He also added that the gaps in collaborations between academia, startups, and industry are currently fragmented in the Indian biotech sector and that effective DBTL workflows require strong coordination between these elements. "The regulatory framework is still evolving around novel synthetic biology techniques, which can slow down DBTL-driven innovations. In terms of data infrastructure, the lack of a centralised data repository and bioinformatics platforms makes the learning phase of the DBTL cycle less efficient. Addressing these challenges through public-private partnerships and targeted government interventions can significantly accelerate the establishment of biofoundries and the adoption of DBTL," he added.

Meanwhile, sharing his views on how biofoundry infrastructure will strengthen the DBTL approach, to drive biotech innovation and high-performance biomanufacturing Dr Dhar said "Biotechnology is often a game of trial and error, relying on a mix of educated guesses and probability. Driven by hypothesis, scientists design a plan of editing cellular traffic, based on past experience, and hope to get predicted results. Even today, genetic engineering is still largely probability-driven. But with the pressure to deliver faster results, there's a need for a more precise, engineering-focused approach to turn ideas into outcomes more quickly. This is where DBTL cycle within a biofoundry comes in."

Dr Dhar pointed out that the biofoundries are revolutionising how we innovate in biotech. With automation, AI, and robotics at the forefront, they enable researchers to test a wide range of ideas at an accelerated pace. This not only improves the Design phase, where new biological systems are imagined and refined, but also brings precision and speed to the entire process. By allowing for high-throughput experiments and rapid prototyping, biofoundries drastically reduce the time it takes to turn an idea into a real-world product. "The most profound shift happens in the Learn phase. Biofoundries use machine learning to analyse vast amounts of data from experiments, uncovering insights that would be impossible to see manually. This powerful feedback loop doesn't just speed up the DBTL process—it also leads to more efficient, sustainable, and scalable manufacturing, ultimately transforming the way we approach biotechnology," he added.

On these lines, initiatives like the BioE3 Policy lay heavy focus on collaborations for bioinnovation and entrepreneurship. Dr Premnath said that the Venture Center brought together stakeholders including industry, academia, startups and suppliers to meet in the run-up to the BioE3 Policy announcement. "These have led to some collaborations and joint programmes to contribute to the goals of the BioE3 Policy. Besides a collaboration between Venture Center and National Chemical Laboratory (NCL), Pune in Biopharma Manufacturing, several industry led and academia partnered initiatives are being planned in the Pune region. The Venture Center also plans to expand its ability to support startups in emerging areas of climate resilient agriculture, food and feed, and industrial biotechnology", he said.

Startup ecosystem will play an important role in these networks. The country's total biotech startup base has expanded to 8,531 companies. The base grew from 3,397 companies in 2019. How this vast startup ecosystem can strategise to leverage biofoundries to innovate in areas like synthetic biology, biopharmaceuticals, and industrial biotechnology can be crucial factors.

Dr Premnath added, "Indian startups need to leverage biofoundries to quickly test out and scale new ideas in emerging areas of market opportunity. Biofoundries can play a useful role after the Proof-of-Concept stage in moving ideas to market faster and in helping generate evidence for feasibility and data for Proof-of-Value. This can be crucial for fund raising for startups. For example, in the biopharma sector, startups will need to have access to platform technologies enabling cell and gene therapy as well as facilities that help companies generate samples for human clinical studies. Pilot scale facilities to scale up synthetic biology-based ideas in producing sustainable ingredients for the FMCG industry will be important."

Establishing and running a biofoundry in India may require more than just financial and technical resources; it could necessitate integrating both physical and digital infrastructures while addressing organisational and operational challenges.

An article titled 'Building Biofoundry India: challenges and path forward' published in Synthetic Biology in 2021, talks about the challenges in the path of building 'Biofoundry India', among other factors. The article highlights that adopting a large resource base in a biofoundry will require re-educating the science administrators, granting agencies, institutions and individual scientists, to embrace shared facilities. The facility must balance providing cost-effective services with offering hard-to-find technical expertise to attract users. BI (Biofoundry India) plans to create several models for client engagement while

maintaining equipment access for internal stakeholders. Additionally, BI aims to work with the Global Biofoundry Alliance to become a leader in software maintenance, support, and data analysis platforms, while addressing long-term challenges like securing and retaining personnel through collaborative projects and career development within the facility.

Catalysts for India's Biotech Future

India is at a crucial juncture in its biotech journey, and biofoundries offer the technological infrastructure needed to take biomanufacturing to the next level. By embracing biofoundry technology and automation, India can strengthen its position as a global leader in biotechnology. “We hope that the biofoundry facilities proposed in the BioE3 Policy will expand the translation capabilities of incubators in the country across multiple sectors”, said Dr Premnath.

Participation in the Global Biofoundry Alliance, combined with national initiatives supporting biotech growth, will enable the country to leverage biofoundries to drive innovation, create sustainable biomanufacturing solutions, and meet growing global demand for biotech products.

On this path, biofoundries will not only enhance India’s biomanufacturing capabilities but also contribute significantly to the country’s broader goals of becoming a biotech powerhouse and a key player in the global bioeconomy.

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