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India's Bioeconomy: A Pathway to Sustainable Growth through Biotechnology

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Abstract: ***The Romer model of economic growth conclusively established that the application of new ideas brings technological progress, resulting in sustained economic growth for an economy. As countries struggle with the problems of hunger, malnutrition, diseases, and environmental degradation, a sector that can provide solutions to all these problems is the biotechnology sector. Biotechnology is a field that uses cutting-edge technologies in the field of biology and chemistry to solve issues in healthcare, agriculture, and the environment. With its vast scientific pool, state-of-the-art biotech infrastructure, and an ever-growing startup ecosystem, India has the required resource endowments to build a strategic economic advantage for itself in this area. The COVID-19 pandemic saw this sector play a vital role in developing indigenous vaccines and diagnostic kits to meet domestic needs and fulfill demands from the rest of the world. India's bioeconomy, i.e., economic activities based on biological resources, has shown robust growth in the last few years, and today India is one of the top 10 BioEconomies globally. This study explores the growth of bioeconomy since 2015, highlights the importance of biotechnology in creating a sustainable development path, and suggests measures to tap the full potential of this sector.***

Keywords: Biotechnology, Bioeconomy, BIRAC, BioE3

1. Introduction

Endogenous growth models highlighted the role of ideas and inventions in generating sustained economic growth. While researchers are coming up with new ideas in almost all areas of knowledge, it is now evident that new ideas and the consequent improvement in technology should be such that they create a sustainable path for economic development. Advances in biotechnology are easily amenable to achieving this objective. Though policymakers have always been aware of this sector's potential to drive the growth process in the desired direction, it is in the recent years that advances in the areas of bioinformatics and availability of large data sets that has enabled scientists to unlock this potential and develop solutions tailored to specific problems in healthcare, agriculture, industry and environment. Ideas are non-rivalrous. In contrast to other economic goods that exhibit rivalry in consumption, once developed, ideas can be put to use by many users. While a large population in a growing economy provides the required market for a new product, skilled manpower in biological sciences, world-class and state-of-the-art infrastructure, and an entrepreneurial spirit give us a definitive advantage in promoting this sector.

2. Literature Review

Researchers have analysed different aspects of the bioeconomy sector to identify strategies for promoting this sector. Lokko et al. (2018) highlighted the importance of industrial biotechnology in generating inclusive and sustainable industrial development, especially for less developed countries, and advocate public-private partnership (PPP) for setting up these industries. Gartland & Gartland (2018) also endorsed the PPP mode and identified genomics, healthcare diagnostics, synthetic biology, gene editing, and bio-digital technologies as areas that provide excellent opportunities for research and innovation.

Oehmke et al. (2001) developed a model to analyze the impact of consumer preferences in the European Union on production, consumption, and R&D in the biotechnology sector, as well as on trade and economic growth. The authors argued that establishing the necessary legal infrastructure in developing countries would help them become major producers of biotech agriculture products. Traxler (2003) in his study noted that most farmers in developing countries do not have access to transgenic crops, i. e., crops that have been genetically modified to enhance required characteristics or delete undesirable traits, and suggested ways to ensure the availability of new technology, especially to small farmers in developing countries. The study also analysed the impact of transgenic crops in cotton and soybeans on the use of chemical pesticides and herbicides.

Tylecote (2019) showed that the biotechnology sector has the required technology to drive economic growth, and reforms in the socio-institutional framework are required to realise its full potential. The author argued that both green (plant breeding) and white (industrial) biotechnology are important in tackling issues related to climate change.

Haaf et al. (2020), in their report prepared for the European Association for Bioindustries, evaluated the economic impact of the biotechnology industry on the member countries. The report highlighted the contribution of the biotechnology industry to GDP, job creation, and export earnings, and also noted that the productivity level in the biotechnology industry is much higher than that in the telecommunications and finance sectors. Eversberg et al. (2023) note that in recent years, policymakers have moderated their expectations from bioeconomy as the driving force behind future economic growth and stressed the importance of considering growth in bioeconomy as one factor among many for social and ecological transformation of the existing modes of production.

3. Methodology

This study uses a descriptive approach to highlight the role of bioeconomy in generating a sustainable growth path. Using

the data published by the Biotechnology Industry Research Assistance Council (BIRAC) in its annual 'India Bioeconomy Report' for the various years from 2015 to 2025, the study examines the trends in value generated and composition by segments for the Indian bioeconomy for this period.

4. Results and Discussion

The subject matter of biotechnology refers to the use of biological processes, systems, and organisms to tackle problems in healthcare, agriculture, industry, and the environment. Bioeconomy is a broader term that focuses on creating a sustainable economic system by using biological resources to produce goods, services, and knowledge.

4.1 Biotechnology and its Applications

4.1.1 Biotechnology and Healthcare

Over the years, several pathogens have acquired resistance to existing drugs. This results in longer and often failed treatments for these infections. A direct impact of this is on the loss of productive manpower and sometimes human life. Many of these diseases, such as tuberculosis, leprosy, and HIV, also have adverse socio-economic impacts, often leading to ostracization of the affected persons and their families.

The biotechnology industry was at the forefront of fighting the recent COVID-19 pandemic and developed vaccines via the use of cutting-edge biotech tools like genetic engineering and cloning. The very diagnosis of the SARS-CoV-2 infection was based on biotechnology in the form of Reverse Transcription Polymerase Chain Reaction or RT-PCR. Since every lab in every country in the world relied on RT-PCR, newer, faster, and cheaper alternatives were the need of the hour. Low-cost antibody and antigen detection kits and easy-to-store and transport diagnostic kits were developed within a record period, which proved instrumental in the proper and early diagnosis of infections.

4.1.2 Biotechnology and Agriculture

Feeding a burgeoning population has always been a challenge for our policymakers. Using advances in genetic engineering, new varieties of crops have been developed that are resistant to specific plant diseases and pests. Similarly, by deleting undesirable genes and enhancing the expression of the desirable ones, through gene editing techniques, better food crops that are resistant to pests and/or high-yielding varieties are being developed. Using such approaches, allergens in crops like wheat, rice, tomatoes, peanuts, etc. have been successfully reduced. With an increase in awareness among consumers regarding the food they consume, the food industry has to constantly innovate and produce products that are both healthy and tasty. Here again, scientists have put biotechnology to use, and have, for instance, developed cooking oil with a lower level of saturated fats; and have created 'super foods" that help the body fight diseases.

4.1.3 Biotechnology and Industry

Biotechnology is used extensively in chemicals, drugs, food, beverages, pulp and paper, polymers, and textiles industries to produce goods with fewer resources and minimal environmental damage. The use of biomass as an alternative energy source to fossil fuels has considerable economic value. The use of organic matter like plants and animals to produce heat or biofuels through processes like combustion, fermentation, etc., creates not only an environmentally friendly but also a sustainable source of energy.

4.1.4 Biotechnology and Environment

Biotechnology has also been put to use to tackle soil pollution in a cost-efficient manner. Genetically modified plants that absorb pollutants from the soil and store them within themselves are increasingly being used to improve soil quality. Advances in plant sciences have also enabled scientists to develop sturdier plants that are less resource-intensive in terms of water, fertilizers, and labour, and can be cultivated in less than ideal habitats.

4.2 Bioeconomy

Recognizing the need for a sustainable growth model, countries all over the world are promoting economic activities that are based on biological resources and are thus creating a vibrant bioeconomy. The BioE3 policy approved by the government of India in October 2024 is designed to promote biotechnology for the economy, environment, and employment. Implementation of the BioE3 policy would involve tie-ups between academic institutions, industry, private investors, and foreign corporations. This strategy would contribute significantly to green growth and job creation and help propel the Indian economy on a sustainable path of structural transformation and economic development. Further, this sector has the potential to earn foreign exchange not just through exports of its products but also via foreign investments in Global Capability Centers (GCC) in life sciences.

The production processes covered under bioeconomy can be divided into primary bio-based, secondary bio-based, and tertiary bio-based segments. The primary production involves the direct use of biological resources to grow crops, raise animals, etc. The output at the start of the value chain is raw biological materials. These are then transformed into goods for final consumption, like food items from raw agricultural products, or generating products like biofuel, biochemicals, and bioplastics in the secondary production stage. The tertiary bio-based production includes the final processing, transporting, and selling of bio-based products to end users. This segment also generates knowledge, digital tools, and protocols for technology transfer.

Economic activities identified as belonging to bioeconomy are grouped into four categories, namely BioAgri, BioIndustrial, BioPharma, and BioIT/Research Services/ BioServices.

The BioAgri division includes genetically engineered plants, bioproducts, biofertilizers, biopesticides, and biostimulants-all of which play a vital role in our efforts to attain food security and sustainability in agriculture. The BioIndustrial segment is one of the major contributors to the generation of value in the bioeconomy. Textile, paper and pulp, alcoholic beverages, leather, and many other industries use enzymes and microbes to accelerate biochemical reactions, and the

products produced using such catalysts are covered under this segment.

BioPharma is another major contributor to the growth of the bioeconomy. It includes the development and production of pharmaceuticals, vaccines, medical devices, and diagnostic kits. This sector showed impressive growth in the post-2019 period, as it not only fulfilled the domestic demand but also supplied much-needed COVID-19 vaccines to the world. Today, India is one of the largest producers of vaccines and generic medicines in the world.

BioIT/Research Services/BioServices includes CRO (Contract Research Organizations) that undertake clinical trials for vaccines and drugs developed in research labs and institutions, and CDMO (Contract Development and Manufacturing Organizations) that take care of the development and manufacturing of drugs. Another important constituent of this segment is BioIT, which refers to IT tools used in biological research.

4.3 Size and Growth of the Bioeconomy

The size of the bioeconomy has grown from a modest $2 billion in 2003 to $10 billion in 2014 and further to an impressive $165.7 billion in 2024. Table 1 shows the growth of the Indian bioeconomy since 2015. The share of the bioeconomy in India's GDP has steadily increased over time and, as of 2024, accounts for 4.25% of GDP.

Table 2 gives the contribution of each segment in the total value created by India's bioeconomy. From Table 2, it is clear that BioPharma has consistently had one of the highest shares of the total value created. In recent years, BioIndustrial has picked up and is now the largest contributor in value terms. It is to be noted that the value of Bioindustry and hence the total value generated in the bioeconomy was revised in 2023 for the years 2020, 2021, and 2022 to include products that used enzymes as catalysts in the bioindustry segment. The other two segments, namely BioAgri and BioIT/Research Services/BioServices, have shown a gradual increase in value creation. The additional segment of the COVID economy records the contributions from vaccines, testing, and related services undertaken during the pandemic.

Table 1: Size and Growth of Indian Bioeconomy

Year	Size of Bioeconomy Sector	Annual Growth Rate	Share in GDP
2015	$35.1billion	250%	1.70%
2016	$41.6 billion	18.50%	1.80%
2017	$44.47billion	6.80%	1.70%
2018	$51billion	14.68%	1.90%
2019	$62.5 billion	23%	2.20%
2020	$86.0 billion	12.30%	2.70%
2021	$106.3 billion	14%	2.80%
2022	$137.2 billion	29%	4%
2023	$151.1billion	10%	4.30%
2024	$165.7 billion	9.70%	4.25%

Source: India Bioeconomy Report (BIRAC, Govt. of India)

Table 2: Segments of Indian Bioeconomy

YEAR	BIOAGRI	BIOINDUSTRIAL	BIOPHARMA	CRO/BIOIT/RESEARCH	COVID ECONOMY
2015	$9 billion	$1.9 billion	$18.9 billion	$5.3 billion	
2016	$9.8billion	$2.6 billion	$23.8 billion	$5.5 billion	
2017	$10.3billion	$2.9 billion	$24.3 billion	$7 billion	
2018	$11 billion	$4 billion	$28 billion	$8 billion	
2019	$12 billion	$5 billion	$36 billion	$9.8 billion	
2020	$11.1 billion	$ 20.9 billion	$38 billion	$10.5billion	$5.5 billion
2021	$10.5 billion	$36.4 billion	$39.41 billion	$5.4 billion	$14.6 billion
2022	$11.5 billion	$59.0 billion	$49.8 billion	$9.3 billion	$7.7 billion
2023	$12.4 billion	$72.6 billion	$53.8 billion	$12.1 billion	
2024	$13.5billion	$78.2billion	$58.4billion	$15.6 billion	

Source: India Bioeconomy Report (BIRAC, Govt. of India)

4.4 Factors Responsible for the Growth of Indian Bioeconomy

Over the years, several government departments have been created that promote the use of biotechnology in improving human lives. The Department of Biotechnology (DBT) and the Department of Science and Technology (DST), both under the aegis of the Ministry of Science and Technology, are two key departments that cater to the use of biotechnology in improving healthcare. In addition, the Indian Council of Medical Research (ICMR) under the Ministry of Health is a key organization that oversees medical research and regulatory aspects of new drug and vaccine trials. A third organization that bridges science and industry is the CSIR-Council for Scientific and Industrial Research. All four organizations, namely, DBT, DST, ICMR, and CSIR, have several research institutes under their umbrella that pursue research in multiple fields, including biotechnology, to develop solutions to challenges in healthcare, agriculture, and the environment. All these institutes, together with Central and State-level universities, have played an important role in creating a skilled workforce–the lifeline of this sector.

During the year 2012, DBT established the Biotechnology Industry Research Assistance Council (BIRAC) to support and empower new biotech ventures. BIRAC plays an important role in advocating policies to strengthen the biotech ecosystem in India. It has also established Bio-incubation centers, which help startups carry out research and development. Research work in India covers basic and translational research and is often a collaborative effort between academia and industry, thus putting the available resources to optimal use.

4.5 Financing the Indian Bioeconomy

The government of India has given a lot of impetus to developing various aspects of biotechnology. Over time, the

budget outlays for research that focuses on developing different diagnostic tools, innovative techniques for drug and vaccine development have shown a steady increase. Financial Support by government agencies like DBT, DST to promote R&D in biotech, Biomanufacturing, and entrepreneurship is given under schemes like BioE3, Bio-Ride, Vigyan Dhara, etc.

Under the BioE3 policy, financial support for R&D, setting up of Biomanufacturing and Bio-AI hubs, and Biofoundaries is given by DBT and BIRAC, along with contributions from the private sector, and it is implemented in a PPP (public-private partnership) mode. State governments are encouraged to set up BioE3 cells in their respective states to harness the all-around benefits of advances in biotechnology.

The DBT-BIRAC runs the Biotechnology Research Innovation and Entrepreneurship Development (Bio-RIDE) scheme, which provides financial support for setting up Bio-AI Hubs, Biofoundaries, and Biomanufacturing Hubs, thus facilitating researchers to convert their new ideas into marketable products. Vigyan Dhara is another important scheme introduced by DST, which aims to enhance the research capacity, both in terms of infrastructure and skilled manpower, and supports the development of indigenous technologies, startups, and entrepreneurs.

BIRAC also provides financial assistance through programs like Bioincubators for Nurturing Entrepreneurship for Scaling technologies (Bio-NEST), Biotechnology Ignition Grant Scheme (BIG), and Small Business Innovation Research Initiative (SBIRI). Under the Bio-NEST scheme, assistance for incubation space for startups is given. The BIG scheme provides funds to biotech startups and scientist-entrepreneurs to help them commercialize their discoveries. Similarly, SBIRI provides a grant-in-aid up to Rs.50 lakhs for early-stage pre-proof-of-concept research, with high-risk innovative research by small and medium companies being given priority. BIRAC's equity schemes, like the Support for Early-stage Entrepreneurs for Discovery (SEED) Fund, LEAP Fund, and Accelerating Entrepreneurs (AcE) Fund, also provide the required capital for biotech startups. Another platform through which BIRAC provides early-stage investment in biotech startups is the BioAngels platform-a collaboration between BIRAC and Indian Angel Network (IAN).

The private sector has also pumped in resources. Corporate entities like Reliance, TATA, and Biocon have also played a proactive role in developing a dynamic startup ecosystem by financing, mentoring, and providing essential facilities to the startups. Investments through Private Equity (PE) and Venture Capital (VC) fluctuated over the period 2015-2022, reaching $728.87 million in 2018, and again, after a dip in the subsequent two years, were at $789.94 million and finally peaked at $938.77 million in 2022. While data for the years 2023, 2024 are not available from BIRAC's website, its India Bioeconomy Report 2025 notes that Health-Tech accounted for 29% of total PE investments in 2024 as digital health platforms and telemedicine became popular means for acquiring healthcare services. The biotech industry also increased its allocation for R&D. During the COVID pandemic, it spent close to 5% of its turnover on developing vaccines and other products.

The collective efforts by the government and the private sector in promoting startups have resulted in the number of startups increasing from a modest 732 in 2015 to a respectable 10, 075 in 2024. Though startups have come up in all the segments, Biopharma has the largest number of startups.

4.6 Challenges for the Indian Bioeconomy and the Way Forward

India, today, has a very large bioeconomy. But in terms of the share of this sector in GDP, it has a long way to go before this figure matches the shares registered by countries like Spain, Italy, France, and Germany. To create a bioeconomy for sustained economic growth, there is a need to increase the outlays for biotechnology at various levels. Important steps that need to be taken to achieve this goal include

1) Creating more world-class research institutes,
2) Increasing funding to existing institutes and universities for upgrading infrastructure, c) training more manpower for quality research by increasing the number of fellowships for doctoral and post-doctoral research,
3) Giving incentives for developing translational lab-to-bench products like vaccines, diagnostic kits, and drugs,
4) Encouraging academia-industry research collaborations,
5) Creating bio-incubators for testing of technology platforms developed in research labs that can be taken up for scaling up,
6) Identifying areas that require immediate attention, like large-scale sequencing of genomes of pathogens that cause infections across the length and breadth of the country (an exercise that proved valuable during the covid-19 pandemic),
7) Creating platforms for state-of-the-art gene therapies like car-t cell treatment for cancers,
8) Increasing the productivity of cash crops that may push up exports of exotic plant products,
9) Improving animal health by tackling cattle-borne infections and promoting measures to increase milk and meat production.

5. Conclusion

Availability of skilled labour, a growing entrepreneurial class, infrastructural facilities that allow use of cutting-edge technology, and above all, investors, whether government or private, willing to provide the much-needed capital, indicate that India is poised to harness the bioeconomy sector for sustained economic growth. Policy initiatives by the government further ensure the right environment for the continuous growth and development of this sector.

However, many challenges have to be overcome before we can fully leverage biological resources. The ones that need serious attention are funding for research, creating infrastructural facilities, and support for entrepreneurship. There is an urgent need to make research an attractive career opportunity for our youngsters by setting up more research institutes and encouraging the private sector to allocate more resources for R&D through various tax incentives. The regulatory system needs to be reformed to create a research-

friendly setup. Collaborations, at the national and international levels, between academia and industry will help researchers share expertise and infrastructural facilities and work on bioeconomy initiatives.

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