RIS Discussion Paper # 338

# Evolving Bioeconomy Policy Discourse: An Assessment of Trends and Drivers

**Amit Kumar and Anupama Vijayakumar**

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Amit Kumar* and Anupama Vijayakumar**

***Abstract***: The notion of bioeconomy has been gaining traction within the global policy discourse on sustainable development and climate change in the 21st century. Essentially referring to an economic production model based on sustainable use and conservation of biological resources, the activities in a bioeconomy are propelled forward by advances in fields including modern biotechnology and Synthetic Biology. The growing interest in this evolving policy paradigm has been evidenced by several countries from the Global North as well as the Global South proceeding to craft bioeconomy strategies in light of their respective capabilities. In recent times, this translated to the Brazilian Presidency of the G20 in 2024 initiating the G20 Initiative on Bioeconomy (GIB), resulting in the G20 nations agreeing upon ten high-level principles accommodating diverging bioeconomy policy visions. While the G20 Rio Summit represented a starting point for building consensus on the various dimensions of the paradigm, nuances within global bioeconomy governance including for formulating sustainability standards and measurement frameworks to facilitate trade in bio-based resources, were taken up during South African G20 Presidency in 2025. This discussion paper seeks to critically analyse the evolving global policy trends in bioeconomy while outlining the convergences and divergences among bioeconomy strategies formulated by OECD and non-OECD countries. The emerging academic and policy discourse on the subject have been captured. It shall attempt to situate India's bioeconomy vision and priorities within the global context. It finally identifies specific areas in which the G20 and other multilateral bodies should prioritise to carry the policy discourse forward.

***Keywords*****:** Bioeconomy, Biotechnology, G20, India, Sustainable Development, BioE3 Policy

## Introduction

Bioeconomy has rapidly evolved as an overarching policy paradigm in the 21st Century. A concept originating in the mid-1990s, bioeconomy in simple terms refers to a novel production paradigm which places at

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its centre the "production, utilisation, conservation and regeneration of biological resources" (FAO, 2023). The existing global consensus on bioeconomy further regard it as a knowledge-based economy primarily propelled forward by the advances in biotechnology. has gained substantial global traction as a paradigm which holds the key to solving major existential crises facing humanity.

Particularly in the recent past, bioeconomy has come to be regarded at high policymaking circles as "a pivotal strategic instrument" that can help attain internationally agreed upon climate goals (IACGE, 2024). Bioeconomy policies help attain internationally agreed-upon climate goals, such as the Paris Agreement targets and net-zero emissions by within a time line say by 2050 or earlier, by fostering a shift from fossil-based to renewable, biological resources. These policies promote sustainable agricultural practices, advanced biofuels, and bio-based materials that reduce greenhouse gas (GHG) emissions, enhance carbon sequestration, and improve resource efficiency across sectors.

Through bioeconomy strategies countries seek to bring about a multiplier effect. This is done so through aligning bioeconomy priorities with long-term sustainable development strategies. The meta discourse on bioeconomy has further come to be regarded as "one of the most pertinent policy trends and undercurrents within which agricultural and forestry choices are situated" (Ollinaho & Kroger, 2023, p. 1) More significantly, the activities envisaged under bioeconomy have come to be regarded as integral to sustainability goals while also offering the means to address challenges to food, energy and environmental security (Congressional Research Service, 2022). In the long run, this paradigm is expected to pave the way for sustainable and inclusive economic transformation.

The emphasis on future development for pushing up bioeconomy is different in different regions and countries. The stress on mastering biotechnological capabilities is also dissimilar, and is tuned with the local technological capabilities. The developments in bioeconomy plans and programs in the European Union, UK, USA, China, India, Japan, Brazil, ASEAN countries, South Korea and Russia have been studied and compared in a study. The study also revealed that the Australian

plans and programs are strongly leaned towards using techniques relevant to synthetic biology. Further, it has been revealed that advancement in wealth creation by developing products involving the manipulation of genes, cell lines, and natural life forms has strong societal acceptance issues. It has been suggested that the elements of ethics and social acceptance issues, including rights to choose and legal provisions, need to be worked upon through united global forums on a precautionary principle for an undisputed sound resolution (Khandekar and Ghosh, 2023).

Being an integrated policy framework can tackle multiple interlinked challenges, bioeconomy has received substantial attention among the emerging economies in the Global South. Often possessing a lower level of technological and financial capacity compared to their counterparts in the Global North, countries in the Global South have arguably employed the paradigm to "address persistent social and economic challenges and usher in immediate change" (International Advisory Council on Global Economy, 2024). The evolving discourse on bioeconomy policies in the Global South in this regard often identify unemployment, poverty and biodiversity degradation as challenges to be tackled. In particular, some of the leading technology leaders hailing from the Global South, including India, China and Brazil have sought to capitalise upon their niche strengths in biotechnology to enhance their overall economic power profiles. While employing biotechnology to address domestic requirements, these nations have also sought to achieve self-reliance through reducing costly imports.

Through achieving indigenous capacities, they have sought to enhance their reputation and bargaining power in global governance forums, while negotiating with the Global North from a position of strength (Vijayakumar, 2024) . The BioE3 (Biotechnology for Economy, Employment and Environment) policy announced by the Government of India in 2024 can be seen in this light. The policy is geared towards helping India emerge as a global leader in the next industrial revolution. The policy lays impetus on biomanufacturing to set India on a path of "accelerated green growth". Such interventions are intended to address

continuing social, economic and environmental challenges as a means to bring about tangible changes such as creation of jobs.

This can best be understood by assessing the policy impetus India has been placing on sustainable fuels. An important focus of India's National Biofuels Policy in this regard has the use of absolute alcohol (anhydrous ethyl alcohol) in petrol. India is resorting to blending absolute alcohol in petrol (gasoline) from about 10 % ethyl alcohol by volume to up to 20 % by volume in order to save in the use of fossil fuels; the requirement of fossil fuels is met in the country sizably through imports. Further , fossil fuels are fast depleting and therefore use of ethyl alcohol, which is produced from sugar( sucrose) by fermentation makes some sense. Production of sugar from sugarcane juice is a kind of renewable source, and therefore it is an intelligent wisdom for the time being in the country. This process of using absolute ethyl alcohol in petrol (gasoline) falls under "blending technology".

Meanwhile, biodiversity conservation and its social benefits have been highlighted within bioeconomy strategies emanating from the Latin America and the Caribbean (LAC). Moreover, a general lack of assessments on bioeconomy policies emerging from the Global South has been termed a "major knowledge gap" within the existing discourse (Giurca, Lehmann, Rodríguez, Sinaga, & Kleinschmidt, 2023).

In this regard, a broad consensus exists within the academic and policy circles as to the larger vision attached to the bioeconomy paradigm. However, an analysis of bioeconomy strategies formulated by countries from the Global North and the Global South reveal major divergences as sated earlier. Such divergences often spring from varying perceptions on how biological sciences or resources link to economics. The divergences can also be alluded to nation-states' interpreting bioeconomy in light of their respective priorities, available natural resources and technological capabilities. These divergences are visible at the conceptual, definitional and extend to methods utilized in bioeconomy measurement as detailed in Section III of this discussion paper.

It is in this context that Brazil, as a part of its 2024 G20 Presidency drew attention towards the need to integrate this novel yet promising paradigm into the ongoing discussions on global economy and

cooperation. Brazil in effect utilised its G20 presidency as an effective forum for bioeconomy to gather sufficient policy momentum. In this regard, the Brazilian Presidency successfully steered the work programme of the G20 Bioeconomy initiative (GIB) to arrive at ten High-Level Principles on Bioeconomy. These high-level principles represent the first and only multilateral consensus on the matter from the point of view of global governance of bioeconomy. The principles have also taken into account an extensive breadth of considerations some of which had been outlined during the preparatory phases. The principles in addition to imbibing certain convergences in bioeconomy visions and goals have also sought to outline key priorities that require global policy intervention and coordination and cooperation. Principle 8 for instance, highlights the need to "utilize transparent, comparable, measurable, inclusive, science-based and context-specific criteria and methodologies to assess the sustainability of products and services in a bioeconomy throughout the value chains" (G20 Initiative on Bioeconomy, 2024).

Under South Africa's 2025 G20 Presidency, the G20 Initiative for Bioeconomy (GIB) gained significant momentum, focusing on translating the prior year's High-Level Principles into practical action to build a sustainable, inclusive, and climate-resilient bioeconomy, leveraging Africa's rich biodiversity for low-carbon growth, food security, and innovation through strengthened global cooperation and shared standards. Key discussions centered on creating common frameworks for monitoring, addressing financing gaps in the Global South, and ensuring the bioeconomy supports livelihoods and biodiversity conservation, with strong emphasis on regional African opportunities.[1]

Considerations of significance from a global governance perspective also range from definitional and metric related issues to implementation mechanisms including food and nutritional security and financial and monetary regulation. Moreover, an assessment on the G20 members' bioeconomy strategies indicates a major synergy existing across three thematic axes namely: biotechnology (research, development and innovation), bioresources (sustainable use of biodiversity) and bioecology ( applies to sustainable development in a broad context) (NatureFinance, 2024, pp. 5-6).

Moreover, divergences with respect to bioeconomy measurement frameworks which spring from definitional issues hinder comparability. This is one area that may require concerted focus to enable consensus building. In this regard, this paper firstly analyses India's approach to bioeconomy as a major biotechnology leader in the Global South, while outlining its key priorities and emerging growth trajectory. Drawing from the Indian Bioeconomy Reports, it shall further give shape to India's views and identify its complementarities and differences with other G20 members' bioeconomy strategies. It secondly analyses the global policy trends evolving around bioeconomy as a novel techno-economic paradigm, while situating India's bioeconomy strategy within it. The paper also undertakes a comprehensive assessment of bioeconomy strategies formulated by select governments in OECD and non-OECD countries to elucidate the commonalities and differences between them.The emerging scholarly and policy discourse on the concept of bioeconomy have also been analysed to identify their central focus and key priorities. In conclusion, the paper identifies the issue-areas which require concerted policy focus from the point of view of diplomacy and international cooperation to catalyse bioeconomy as a means to build a sustainable and inclusive future.

## Deciphering India's Approach to Bioeconomy

The Indian Bioeconomy Report (IBER), 2024 define bioeconomy as "*the utilisation of renewable biological resources to produce bio-based products and services. Activities driving the bioeconomy encompass the production, trade, distribution, management and consumption of goods and services derived from biological resources*". (Suresh, Chandan, & Krishnan, 2024, p. 64). However, its view of bioeconomy is dominated by a biotechnological vision as mentioned in Table 1. India views the holistic nature of biotechnology as a means to tackle societal challenges through delivering innovative bio solutions from bioresources to address climate change and a to serve as a vehicle for achieving socio-economic growth. For India, bioeconomy presents the ideal policy paradigm for accommodating its unique civilizational perspectives on a mode of economic production which is in harmony with nature; the ethos that are

basically imbibed in the *Vasudhaiva Kutumbakam* philosophy. Such a view is evident from the National Biotechnology Development Strategy, 2021-2025. The document states its vision as "to harness the potential of biotechnology as a premier precision tool for national development and well-being of society" (DBT, 2020). Herein, sustainable consumption and equitable distribution of benefits, such as through creating jobs assume a central place in India's bioeconomy strategy.

While anchored to a biotechnology-dominated vision, India's bioeconomy policy approach is unique in terms of the priorities identified in light of its national interest and economic orientation. Such orientations are clear from an assessment of the evolution of its biogovernance organizational and policy architectures. Having set up its Department of Biotechnology (DBT) as far back as 1986, India's policymakers have outlined the growth of its bioeconomy as a major policy priority during the second decade of the 21st century. The DBT along with its Biotechnology Industry Research Assistance Council (BIRAC) (created by DBT as a 'not-for-profit' section 25 company to stimulate, foster and enhance the strategic research and innovation capabilities of the Indian biotech industry particularly SME's) has annually published the Indian Bioeconomy Reports (IBER) which detail the contribution of various sub-sectors to fueling an upward growth in bioeconomy. The larger trends evolving within these sectors as well as a snapshot on the outcomes of various policy measures intended to boost growth in bioeconomy are also featured within these reports.

**Table 1: Constituent Sectors of India's Bioeconomy**

| Sector | Constituents | Measurement methodology |
|---|---|---|
| Biopharma<br><br>(medicines made using living cells, organisms, or biological processes ) | Sera and Vaccines | Total supplies: production plus imports |
| | Therapeutics (r-DNA proteins, conjugates & derivatives) | Data insights from EY and IQVIA + import & export data |
| | Diagnostics | Revenue size of test |

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| | | |
|---|---|---|
| Covid Economy** | Covid vaccines | Same as vaccines and diagnostics mentioned under biopharma. |
| | Covid testing | |
| Bioagri | Bt Cotton | Value-added should be on the direct industrial outputs at primary sources. |
| | Plant Tissue culture<br>Biofertilizers<br>Biopesticides & others | |
| Bioindustrial (enzymes for food processing, textiles, detergents, tannery, paper-pulp making etc. & processed triglycerides as biofuels) | Multiple Types of Enzymes | Data provided by the Ministry of Consumer Affairs, Food & Public Distribution, Indian Sugar Mills Association, Tanneries, Detergents manufacturers, Paper pulp industry, Environment management companies etc. |
| | Biofuels | Modified Triglyceride Oil Manufacturing & Marketing Companies |
| BioIT | Usually expenses on such activities get aggregated within R&D expenses of manufacturing companies | Aggregating revenues of Contract Research Services & IT Firms with Life Science Practices |

* Biopharmaceuticals, bio-agriculture, bio-services and bioindustry, have been included under biomanufacturing within the 2021 "Report on Assessing the Regional Competitiveness of the Indian Bioeconomy: Moving towards a sustainable circular model" published by BIRAC and Institute for Competitiveness.

** Covid economy has been considered as a separate sector of bioeconomy within IBER 2022 and 2023. This is indicative of the growth that the Indian bioeconomy witnessed due to Covid-19 testing and vaccine drives.

***Source:*** BIRAC. (2022). India bioeconomy report 2022. Retrieved from BIRAC: https://birac.nic.in/webcontent/1658318307_India_Bioeconomy_Report_2022.pdf; BIRAC. (2023, December). India bioeconomy report, 2023. Retrieved from BIRAC: https://birac.nic.in/webcontent/India_BioEconomy_Report_2023.pdf

The IBERs further provide insights into India's approach to measuring growth in bioeconomy, The anchoring of India's bioeconomy strategy in a biotechnology-oriented vision is further evident from its labelling of sectors that constitute it. These effectively represent India's niche strengths in biotechnology. Such an approach has become particularly evident within India's evolving perception on bioeconomy in the post-pandemic era. As indicated in IBERs published since 2020, India's bioeconomy consists of five sectors: Bioagri, Biopharma, BioIT, Bioindustrial and Covid economy. However, India's approach to bioeconomy can be identified to stand on two pillars: knowledge including innovation and manufacturing. The two pillars serve to pave the way forward for India to become self-reliant in line with the objectives outlined under "Aatmanirbhar Bharat".

The DBT has earmarked the period during 2021-2025 for steering biotechnology advances to contribute to a "knowledge and innovation driven bioeconomy". The goals formulated in light of the boom that India's bioeconomy witnessed during the pandemic, lays emphasis on capacities as pertinent to human resource and infrastructure and strengthening various components of the ecosystem, while also addressing the disconnect between basic and translational research.

Herein India is noted to have evolved as the pharmacy of the world in recent times and ranks "third globally in drug and pharmaceutical production by volume" (PIB, 2024). India is called the "Pharmacy of the World" because it's a leading global supplier of affordable, high-quality generic medicines, vaccines, and pharmaceuticals including life-saving drugs, and known for its massive production scale, cost-effectiveness, stringent FDA/WHO compliant quality standards, and ability to meet global demand. During health crises like COVID-19 India was able to supply vaccines at affordable costs locally as well as for the developing nations. Biopharmaceutical drugs are a small portion of the total drugs and pharmaceuticals manufactured in the country. Drugs and Pharmaceuticals manufactured in India was the result of continued Government support and pressure to manufacture medicines including active pharmaceutical

ingredients(APIs) , locally , and as far as possible from the basic stage, using as much as possible local materials (Ghosh, 2019). As mentioned ,not all the drugs and pharmaceuticals manufactured in India are biotech drugs. The Indian biopharmaceutical market was approximately INR 32261 crores (US$ 4.032 billion) during 2021–2022 and approximately 1.14% of the global biopharmaceuticals market (Ghosh, 2023).

The manufacture of biopharmaceuticals needs sophisticated equipment and specialized skills. India was manufacturing a couple of antibiotics, a number of vitamins and a few steroids by using fermentation techniques earlier, during the period from 1954 up to the middle of 1991; during these periods fermentation-based APIs were added gradually over the years, primarily due to the policy pressures, from the Indian Government besides Government's protecting local production of fermentation-based APIs by extending cost plus prices in deciding the selling prices of such APIs. Later, India acquired skills in recombinant deoxyribonucleic acid (rDNA) technologies from early nineties, developed capacities in genetically modifying Escherichia coli, Saccharomyces cerevisiae, Pichia pastoris, Hansenula polymorpha, and Chinese hamster ovary (CHO) cells lines, and developed expertise in the multiplication of viruses in different animal and human cell lines. Considerable basic skills were acquired by the country for the basic manufacture of a number po patent-expired rDNA- based drugs.

India presently produces several therapeutic and diagnostic recombinant proteins, including several therapeutic monoclonal antibodies. The skills acquired were commendable though the advanced countries made much higher technological progress during this period. The more advanced areas of biopharmaceutical technology, such as mRNA-based cell therapies, including in-vitro modified somatic cell-based treatment and chimeric antigen receptor (CAR) T-cell therapy, are fast evolving globally. Genome editing technologies involving the manipulation of germ line cells are in the advanced research and development (R&D) stage, while certain products are also appearing commercially in other parts of the world. Xenotransplantation technologies and the development of humanized transgenic animals are

yet to start. In these areas, Indian developments have not yet been able to catch up in global context. Further, appropriate artificial intelligence programs may also be included in the Indian biopharmaceutical industry to speed up the development of novel biopharmaceuticals. The outputs of activities embedded in the manufacture of pharmaceuticals utilizing the above processes and techniques are considered to fall under advanced biopharmaceuticals technology.

The present turnover (2024-25) of Indian Pharmaceutical Industry, which includes the turnover of biopharmaceuticals industry, is estimated to be about US$56.97 billion of which US$ 5.84 billion is anticipated to be contributed by the present Indian biopharmaceuticals industry (Ghosh, 2024a, 2024b).

As such, the present biotechnology industry growth in India is said to have been "primarily driven by vaccines and recombinant therapeutics" (Department of Biotechnology, 2020). Most of the fermentation-based complex bio-pharmaceuticals producing companies could not maintain their production in India, and had to close down because of withdrawal of the earlier cost plus prices in deciding the selling prices of such APIs, by the government. During the period of Covid-19, the manufacture of vaccines got a boost along with the methods of detecting the disease, as the country needed to fight back the disease. Government support for the development of effective vaccines was immense.

After the Government of India approved the Covid-19 vaccines for emergency use in January 2021, "the rate of vaccinations reached a new high" resulting in the sector growing at a stupendous rate. India could succeed in the venture as there was considerable "acquired past knowledge" in the manufacture of conventional deactivated microbial vaccines technology. The major supply of finished Covid-19 vaccine for local use was met from the supply of the requirement of the country by a couple of units, and one unit from Pune supplied more the 85 % of the local requirement. However, that phase of crisis is already over, and the capacities created for the manufacture of vaccines has to be diverted for make their efficient use. In the meantime, the biopharma industry as a sub-sector of pharmaceutical industry had been accorded the status of

a “strategic and flagship industry”. To achieve the status, India needs to develop new and cost-effective technologies in multiple sub-sectors as depicted earlier.

India’s bioeconomy has been increasing its share of the national GDP. India’s bioeconomy is estimated to have grown at least tenfold during the 2014-2022 time period. Projections indicate that India’s bioeconomy would quadruple by 2030 to amount to a total of USD 300 billion (Malik, 2022; Dewan, 2023). Biopharma along with the Covid economy further has particular relevance with respect to contextualizing the future projections for growth in India’s bioeconomy. COVID-19 provided a fillip to the growth that Indian bioeconomy witnessed post-2020. Covid economy herein features as a sector constituting bioeconomy within the IBER 2021, 2022 and 2023. This is because the Covid economy boomed during the emergency situation that resulted out of the pandemic. However, by 2023, its contribution declined from 97.4 per cent to 0.2 billion dollars. COVID-19 pandemic in this context can be understood as a “black swan event” and its waning influence is reflected in the reduced bioeconomy growth rate (Naik, Manocha, Valiathan, & Borakoti, 2024). India’s future trajectory in this regard has sought to trampoline from this growth spurt to recalibrate priorities as per the changing global bioeconomy trends. A concerted effort in this regard has been made to provide roadmaps that recommend substitutes.

India's goals in order to do this is to ensure continuous investment in research, better mechanisms for transferring knowledge and for establishing mechanisms that can spur growth in the sector. To enable accurate projections on the size of the biotechnology sector India has formulated a Biotechnology Competitiveness Assessment in 2020.[1] It entails indicators grouped under three pillars, Enablers, Facilitators and Performance. The Competitiveness Framework:

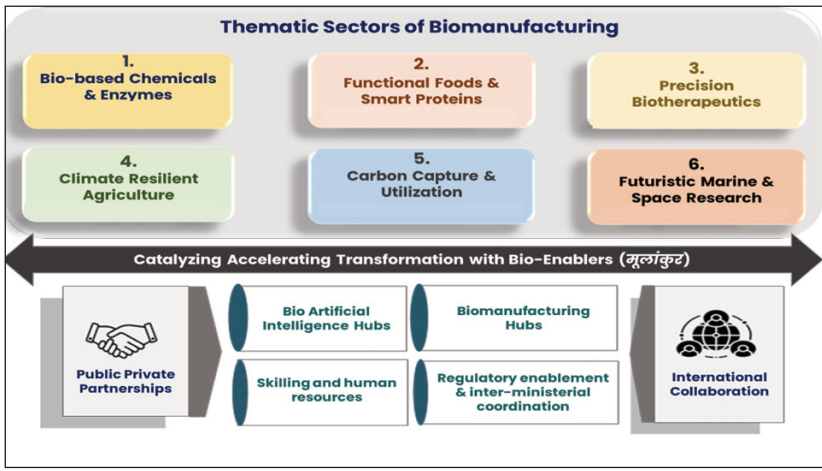
- Compares policy inputs to biotechnology output.
- Input indicates whether a conducive environment for the growth of biotech industry has been created.
- Output- benefits of indicators that can be derived from output.

India is noted to have been performing well in facilitators and has a good global standing in this regard. This is because of India doing well with respect to the development of biotechnology clusters, which have been characterised as a major strength within India's bioeconomy. India is yet to catch up with advanced bioeconomies when it comes to enablers and performance. (BIRAC, 2019)

The launch of the BioE3 policy signifies the growing importance that biomanufacturing has been acquiring within the larger bioeconomy policy calculus. The renewed impetus on bio-manufacturing is happening as the world stands on the cusp of a bioindustrial revolution ushered in by developments in Synthetic Biology (Anton, 2023). This is further indicative of the Government of India recognising biomanufacturing and biofoundry as pivotal to achieving sustainable growth as envisaged under Mission LiFE(Lifestyle for environment). BioE3 represents India's efforts to leverage the enabling potential of biotechnology and synthetic biology to transform multiple sectors of the economy. It further follows a collaborative approach and makes room for government, academia, industry and society to work with synergy in a supportive environment. Within the collaborative approach envisaged under BioE3, the government looks to foster public-private partnerships, inter-ministerial collaborations and international cooperation. It seeks to hasten the pace of advances through setting up bio-enabler hubs, along with intensifying entrepreneurial momentum. The policy further seeks to achieve regulatory harmonisation, including bringing Indian regulation in alignment with global standards and institute an effective and transparent patent system.

IBER 2024 notes the bioindustrial segment to be the cornerstone of India’s bioeconomy and contributes to nearly half of the total bioeconomy. By 2030, the contributions of this sub sector is estimated to grow at a steady compound annual growth rate of 7.5 per cent, to reach USD 121 billions.

## Figure 1: BioE3: Focus Areas and Policy Priorities




***Source:*** (DBT, 2024).

The scheme shall seek to foster high-performance biomanufacturing in areas namely 1. Bio-based chemicals and enzymes; 2. Functional foods and Smart proteins; 3. Precision biotherapeutics; 4. Climate resilient agriculture; 5. Carbon capture and its utilisation; 6. Futuristic marine and space research (Department of Science and Technology, 2024). Emphasis is also being laid on five areas identified as key drivers for future growth including Biosimilars, Therapeutics Innovation, Sustainable Bioindustrial Practices and integration of advanced technologies like bioinformatics, data analytics and AI in bioresearch services (Suresh, Chandan, & Krishnan, 2024, p. 60). India is seeking to leverage the increased demand for bioservices which consist of applications that combine biotechnology with big data and artificial intelligence. In this regard, the BioE3 constitutes a unique and robust policy framework to that can facilitate and leverage the growing convergence between biotechnology, engineering, and digitalization for building a more equitable and sustainable future (DBT, 2024, p. 3). India's focus is on creating a niche in the global market for outsourced R&D services, clinical trials and other specialized services that support the commercialization of biotech.

In alignment with BioE3, the Cabinet has also formulated the 'Biotechnology Research Innovation and Entrepreneurship Development (Bio-RIDE) scheme (PIB, 2024). Bio-RIDE combines two existing schemes: Biotechnology Research and Development (R&D); Industrial & Entrepreneurship Development (I&ED) and adds a third component on Biomanufacturing and Biofoundry. Focused on boosting and fostering the innovation ecosystem, Bio-RIDE is slated to play an important role in helping India grow the size of its bioeconomy to 300 billion dollars by 2030. To achieve this objective, the scheme shall support bio-entrepreneurship, foster industry- academia collaboration and financially support research.

India's policy evolution pertinent to bioeconomy has taken into account timely developments including advances in biotechnology, the advent of AI and related digital technologies, as well as the possibilities emanating from NBIC convergence. Standing on the dual pillars of knowledge and innovation and biomanufacturing, India is seeking to adopt a holistic approach that combines sustainable development priorities with the latest advances in technology. Moreover, India appears to be laying concreted focus on biopharma in trying to keep with its reputation as the "pharmacy of the world".

## Bioeconomy Visions: Commonalities and Differences

The origins of the conceptual linkage between biological sciences and economics have been traced back to the 1960s. Czech economist Jiri Zeman coined the term "bioeconomics" to denote the biological bases that underlie almost all economic activities. The work pioneered by Nicholas Georgescu-Roegen on the environmental implications of unlimited economic growth further allowed such a thesis to gather steam during the 1970s. Meanwhile, the decade of the 1980s saw the emergence of literature on the potential of a biological revolution to transform industrial production processes. However, two geneticists Juan Enriquez Cabot and Rodrigo Martinez have been credited with elaborating upon the knowledge base underlying bioeconomy. Authored by Enriquez, the 1998 article published in the Science magazine titled "Genomics and the world

economy" is often cited as the scholarly origination of the ideas today considered central to bioeconomy. While the article does not feature the term bioeconomy, its presents the notion that the advances in genetics could essentially restructure the world's economy.

However, the emergence of bioeconomy as a major policy paradigm has been attributed to European Commission officials who sought to promote it as a "deliberate decision" However, it was the Concerted efforts made by European policymakers that allowed bioeconomy emerged as a policy paradigm in the early 2000s. Such efforts have been noted to be made as a part of a "deliberate decision" intended to allow the European Union to exploit new opportunities (Birner, 2017, p. 21). As a new political entity, new policy concepts such as the bioeconomy would have particularly been attractive for the EU, as it charted its course toward a futuristic vision. Such thought processes aligned perfectly with Europe's innovation policy which sought to transform the EU into "the most competitive and dynamic knowledge-based economy in the world" (Reillon, 2016, p. 13).

The concerted push for a bioeconomy-based policy framework would culminate in the 2007 Cologne Paper which resulted out of a 2007 workshop held during the German Presidency of the Council of the European Union in the city of Cologne. The paper elaborated upon two perspectives on bioeconomy. On one end, it gave shape to the bioresource substitution perspective by stressing upon the potential for crops to be used as industrial feedstock to produce biofuels and chemicals. On the other end, it attributed a sense of centrality to biotechnology as pivotal to European economic growth and energy security by 2030. However, the resource substitution perspective has dominated bioeconomy policy visions during the 2000-2010 time period. As such, an analysis on select EU member-states' bioeconomy prima facie reveals their anchoring on a bioresource substitution based vision, with sustainability having woven through them.

A number of countries, both emerging and developed economies crafted their respective bioeconomy strategies by the second decade of the 21st Century. While scientists coined the term in the USA also, the Barack Obama administration released its bioeconomy blueprint in 2012.

Stressing on the economic potential offered by "research and innovation in biological sciences", the definition featured in the blueprint also drew attention to how biofuels could potentially serve as an alternative to dependency on oil imports (White House, 2012).

There is no single definition for the parameters or activities that constitute a bioeconomy. Nation-states perceive the idea of bioeconomy in light of their respective priorities, available natural resources and technological capabilities. This gives rise to differences which are reflected across various aspects including bioeconomy definitions, choice of sectors included within bioeconomy calculations (Table 2). These broader differences also extend to the methodologies employed in bioeconomy calculations.

Common features of bioeconomy visions include:

- Bioeconomy as a novel knowledge-based production paradigm.
- Biotechnology as an enabler of bioeconomy.
- Vehicle to achieve sustainable production practices;
- Solution to global challenges including climate change, food security and health security.
- Synonymous treatment with the idea of circular or sustainable economy. Emphasis on the three 'R's: reduction, recycling and remanufacturing of waste materials (BIRAC, 2019)

The US-based National Academies of Sciences Engineering and Medicine (NASEM) categorises bioeconomy visions into three categories: Biotechnology vision, Bioresource vision and Bioecological vision (Congressional Research Service, 2022). Countries who subscribe to a biotechnology vision hold the view that the bioeconomy is primarily enabled by the advances in biotechnology itself. Economic activities within this vision result out of the commercialization of knowledge generated by DNA manipulation and molecular level processes through biomanufacturing. The bioresource vision in comparison revolves around biomass and biological resources which can be processed to yield energy or new products. Meanwhile, the bioecological vision is grounded on

a conservationist view and focuses on biodiversity conservation and the avoidance of ecologically damaging practices. In several cases, bioeconomy definitions entail a combination of strands drawn from all three categorisations.

However, commonalities extend across a broad level within these various definitions. For one, all select nation-states who have formulated bioeconomy strategies view the same as one that pertains to multiple sectors of the economy. All select countries view bioeconomy as a novel knowledge-based production paradigm, while also treating it synonymously with the notion of a circular economy. In this regard, the purpose of the bioeconomy herein is to adapt and provide solutions to address global challenges including climate change, food security and health security while emphasizing on the three 'R's: reduction, recycling and remanufacturing of waste materials (BIRAC, 2019).

**Table 2: Components of Bioeconomy across Select Countries**

| | Bioagri | Bioindustrial/ Biomanufacturing | Biopharma | BioIT |
|---|---|---|---|---|
| USA | ✓ | ✓ | ✓ | X |
| EU | ✓ | ✓ | X | X |
| Japan | ✓ | ✓ | ✓ | |
| China | ✓ | ✓ | ✓ | X |
| India | ✓ | ✓ | ✓ | ✓ |
| Brazil | ✓ | ✓ | ✓ | X |
| France | ✓ | ✓ | X | X |
| Italy | ✓ | ✓ | X | X |
| Finland | ✓ | | X | X |

***Source:*** Authors' own complication based on various sources.

The commonalities and differences that spring from the three bioeconomy vision typologies also extend to the kind of sectors that are included in bioeconomy measurement approaches. In this regard, a notable divergence exists between the bioresource and biotechnology-based visions of bioeconomy. The European Union for

instance, has adopted a broad-based definition of bioeconomy based on bioresources. Consequently, the EU and its member-states include sectors conventionally regarded as primary, including agriculture, forestry and fisheries within its bioeconomy measurement framework. While EU member-states abide by this understanding, variances exist within their individual views. Finland, for instance, interprets bioresources in the broadest sense and accounts for renewable energy sources such as solar and wind in its bioeconomy calculations. Germany's strategy on the other hand while anchoring its definition on bioresources places emphasis on the importance of biological knowledge and the potential opportunities offered by NBIC convergence. A circular economy within this iteration is operationalized by drawing on bioresources to reduce wastage and negative environmental effects. The end-goal herein is to implement sustainability across sectors that contribute to greenhouse gas emissions. However, what sets apart the EU's definition of bioeconomy is a complete exclusion of aspects related to health, medicine and pharmaceuticals from its bioeconomy calculations. This is perhaps because the EU views pharmaceuticals as a critical area of technology where it is trying to regain competitiveness and reduce dependence on external sources (Oscar Guinea, 2023).

**Table 3: Bioeconomy Definitions**

| Country | Definition | Core Priorities | Unique Elements |
|---|---|---|---|
| USA | The infrastructure, innovation, products, technology, and data derived from biologically related processes and science that drive economic growth, improve public health, agricultural, and security benefits. * | Technologies, Infrastructure, Products and Processes concerning bioresources | Biological data &Security |

*Continue...*

*Continued...*

| | | | |
|---|---|---|---|
| UK | Bioeconomy represents the economic potential of harnessing the power of bioscience, using renewable biological resources to replace fossil fuels in innovative products, processes and services | Viewed as a means to replace fossil fuels. | Framing bioeconomy based on economic potential.<br><br>Broad focus on biosciences rather than biotech |
| EU | All sectors and systems which rely on biological resources (animals, plants, micro-organisms and derived biomass), their functions and principles.<br><br>Includes and interlinks:<br>• Land and marine ecosystems & the services they provide.<br>• All primary sectors which use/produce bioresources.<br>• All sectors of the industry that use bioresources and processes to yield products and services. | Focus on primary and secondary sectors | Interlinking of ecosystems |

*Continued...*

*Continued...*

| | | | |
|---|---|---|---|
| Brazil | Novel productive paradigm structured around sustainable use of renewable biological resources and production of goods, services, information and energy. | Bioeconomy as a productive paradigm. | Emphasis on environmental and economic sustainability. |
| India | Bioeconomy encompasses the utilization of renewable biological resources to produce bio-based products and services, and include activities driving the bioeconomy, which encompass the production, trade, distribution, management and consumption of goods and services derived from biological resources. | Biotechnology-centric vision | Emphasis on biopharma as a major segment |
| **International Organizations** | | | |
| OECD | Economic production model within which biotechnology contributes to a significant share of the output. | Biotechnological knowledge, renewable biomass and integration across applications. | Entails a single and a list-based definition. |

*Continued...*

*Continued...*

| | | | |
|---|---|---|---|
| FAO | Production, utilisation, conservation and regeneration of biological resources including related knowledge, science, technology and innovation, to provide sustainable solutions (information, products, processes and services within and across all economic sectors and enable a transformation to a sustainable bioeconomy **. | Use of technology as an enabler of sustainable solutions | Aspect of regeneration of biological resources. |

*The USA has not adopted a comprehensive policy framework concentrated on bioeconomy. The definition was proposed by a 2019 White House Summit, which gathered bioeconomy experts, government officials and industry experts (White House Office of Science and Technology Policy, 2019).

**The FAO has adopted the definition put forth by the International Advisory Council on Global Bioeconomy (FAO, 2023).

***Source:*** Authors' own complication based on various sources.

In comparison, the approach adopted by the USA is dominated by a biotechnology-based vision. Even while considering activities related to primary sectors within bioeconomy calculations, the USA only regards outputs or activities enabled by biotechnology, such as GM crops within agriculture as a part of the bioeconomy. Such an iteration is also in line with the approach delineated within the Frascati Manual, published by the OECD, wherein biotechnology applications are simply included under broad classifications as a second-level classification (OECD, 2015). Further, the biomedical sector is attributed weightage within US

bioeconomy calculations. Such products or applications have to draw from innovations in life sciences. Along with products, medical services that result out of life science applications are also counted as part of the biomedical sector.

The policy debate in the USA on whether primary sectors should be included in bioeconomy calculations is elucidated in the 2020 report titled "Safeguarding the Bioeconomy" published by the National Academy of Sciences, Engineering and Medicine (NASEM). On the pros of adopting a broad definition of bioeconomy, NASEM notes that including primary sectors would facilitate easy measurement since the statistics are often readily available in government records. However, the disadvantage of adopting such an approach may be reflected in the long term. The bioeconomy heavily weighted toward such mature sectors may indicate that the bioeconomy is a shrinking share of economic activity, incomes, and wages over time. NASEM in this regard recommends the adoption of a narrower definition focused on innovation and its applications. The USA's goal in this regard is "to advance biotechnology and biomanufacturing towards innovative solutions in health, climate change, energy, food security, agriculture, supply chain resilience, and national and economic security" (The White House, 2022). A biotechnology-based vision is also followed by countries including Japan and India.

The deeper divergences that spring from definitional differences can be identified from an overall assessment on how the leading countries in biotechnology have categorised their bioeconomy sectors. For the USA, bioeconomy consists of three sectors namely: bioagricultural, bioindustrial and biomedical. The EU on the other hand follows a simplified dual classification approach of the bioeconomy as comprised of "sectors supplying biomass" and "sectors using biomass". Meanwhile, both the USA and China identify biosecurity as a major part of their bioeconomy. Measures instituted to protect against threats to biological security including infectious diseases and terrorism are envisaged as an important part of safeguarding the security of the bioeconomy itself. On the other hand, both primary and secondary sectors are included within the bioeconomy calculations of Brazil and Japan. Given Brazil's niche

strength in biofuels, the country views bioenergy as an important sector within its bioeconomy. Meanwhile, Japan, arguably in a bid to address its ageing problem has articulated “lifestyle-related healthcare improvement including regenerative medicine and gene therapy” as an important part of its bioeconomy, in addition to biopharma.

In India the production, trade, distribution, management and consumption of goods and services derived from biological resources have been emphasized to drive bioeconomy. Special emphasis is on developing bioeconomy in the bio-pharmaceutical sector. In order to become a dominant player in this sector, there is an urgent need to develop technologies in multiple sub-sectors of biopharmaceuticals where Indian capabilities are not yet adequate. These areas include specially the synthetic biology sectors. Synthetic biology techniques encompass a broad interdisciplinary ambit that combines molecular biology, genetics, and systems biology with engineering and computational science. These techniques are often applied through an iterative Design-Build-Test-Learn (DBTL) cycle, utilizing engineering principles like standardization, modularity, and abstraction to create or redesign biological systems.

The core techniques and tools within the ambit of synthetic biology includes Genetic and Genomic Manipulation; use of multiple Computational and Design Tools; utilization of Systems and Metabolic Engineering techniques; modifying "workhorse" organisms like E. coli or yeast to serve as optimized hosts (chassis) for synthetic genetic programs; conducting biological reactions (transcription and translation) in a test tube using cell extracts instead of intact living cells, allowing for greater control and stability; designing biological systems that use non-natural components, such as Xeno-Nucleic Acids; use of next-generation sequencing (NGS) techniques for rapidly reading and verifying synthetic constructs to ensure they match intended designs etc. These technologies are fast evolving globally. Gene Synthesis; DNA Assembly; Bobrick Assembly; Gibson Assembly; Golden Gate Assembly; Genome Editing Tools such as CRISPR-Cas9, TALENs and ZFNs; Prime and Base Editing and Synthetic Genomics involving the

design and assembly of entire chromosomes or genomes, such as the creation of the first synthetic bacterial cell etc. are some of the important techniques used in synthetic biology. Only China has made much progress among the Asian Countries in utilizing certain aspects of synthetic biology techniques for generating value-added biotechnology products. While India is trying to catch up, the country is yet quite behind in proficiently utilizing synthetic biology techniques in diverse areas of applications. In this context the announcement of the Government during the 2026-27 budget is noteworthy.

The government of India Union Budget 2026–27 placed a significant emphasis on the biopharmaceutical sector, announcing the "Biopharma SHAKTI" initiative with a ₹10,000 crore outlay over five years to transform India into a global hub for biologics and biosimilars. Key goals include reducing import dependence, boosting domestic manufacturing, enhancing clinical trial infrastructure with 1,000 accredited sites, and regulatory reforms. In order to achieve the key goals, new and efficient technologies need to be developed in multiple areas of synthetic biology as depicted briefly above (PIB. 2026). Success in achieving the key goals will squarely be dependant upon success in achieving world-class competitive bio-pharmaceutical technologies in the country.

The industrialised nations of the Global North took a leading role in shaping the academic and policy discourse on bioeconomy. However, its implementation, whether guided by an biotechnology innovation or resource substitution often ran counter to the tenets of equity and sustainable development. For instance, facilitating an energy transition by substituting fossil fuels with biofuels has been found to have detrimental impacts on food security (Transport & Environment, 2022) (Koizumi, 2014). According to the FAO, “biofuels demand can lead to higher food prices either through increased competition for inputs such as land, water, fertilizer and labour, or through international trade” (FAO, n.d.). Such impacts of bioeconomy policy implementation in the Global North have arguably been tangibly felt in the Global South. Such impacts may be understood by probing into the 2007 Tortilla crisis which affected Mexico (Thomaz & Carvalho, 2011). The subsidization of ethanol production in

the USA and the resultant increase in demand for yellow corn has been identified as a major reason for the price of tortillas, a staple food in Mexico to rise from 5 dollars a year to 20 US dollars per year. Meanwhile, biofuel feedstock monocultures have often proven to have resulted in destroying biodiversity, otherwise regarded as a bioresource within the bioeconomy paradigm.

In this background, bioeconomy strategies emanating from the Global South, while drawing from the existing typologies are characteristically distinct. Countries in the Global South are often endowed with rich biodiversity and robust traditional knowledge systems which provide guidance on the means to sustainably harness the biodiversity wealth. In several cases, Global South countries have thriving cottage industries and host indigenous populations that value and often rely on biodiversity exploitation for subsistence. According to recent figures, indigenous people amount to six percent of the global population and nineteen percent of the world's extreme poor (World Bank, 2023). In this regard, the bioeconomy strategies emanating from the Global South are often guided by a development first approach (Stockholm Environment Institute, 2018), with sustainability being a theme running constantly through them.

Bioeconomy strategies emanating from Latin America and the Carribbean (LAC), for instance, stress on "biodiversity and ecosystem services". A major bioeconomy leader, Brazil, views bieconomy to "mainstream biodiversity" (Queiroz-Stein, Martinelli, Dietz, & Siegel, 2024). Compared to bioeconomy strategies that are based on biofuel and biomass production, Brazil has laid a concerted focus on grounding its bioeconomy strategy on its biodiversity. Brazil's national bioeconomy strategy entails a combination of the biotechnological, bioecological and bioresource visions The country has evolved its own unique bioeconomy paradigm termed the "socio-biodiversity bioeconomy". This paradigm embodies the values that drove the country's socio-environmental movement in the 1980s. This movement had sought to challenge the capitalist Western discourse on ecological conservation. It essentially pointed out that the discourse had not taken into account social and

economic practices which are non-predatory toward the ecosystem. This paradigm has been situated within Brazil's forest-based bioeconomy policy intended to sustainably exploit the Amazon rainforests. The socio-biodiversity paradigm herein also lays emphasis on economic and social support for indigenous communities. It additionally advocates for the use of biotechnology for improving the efficiency of biomass production and enabling bio-based industrial activities.

Along with Brazil, the modalities of implementation envisaged within Costa Rica's 2020 bioeconomy strategy is regarded by scholars as a good model for Global South countries to follow (Loomis, 2023; Khan, Palmer, & Chang, 2024; Monagas, 2023). Resulting out of an interministerial consultation process, Costa Rica's bioeconomy strategy entails a holistic combination of modern and traditional knowledge. It further lists rural development and urban development within the five strategic areas of focus, alongside biodiversity, biorefinery and biotechnology. The strategy is also notable for inclusion of unique implementation methods which seek to achieve equitable access to bio-based resources and social inclusion (Ministerio de Agricultura Ganaderia de Costa Rica et. al, 2020). The Women Nature and Rural Women Credit is one such program which has sought to encourage female entrepreneurship through bioeconomy.

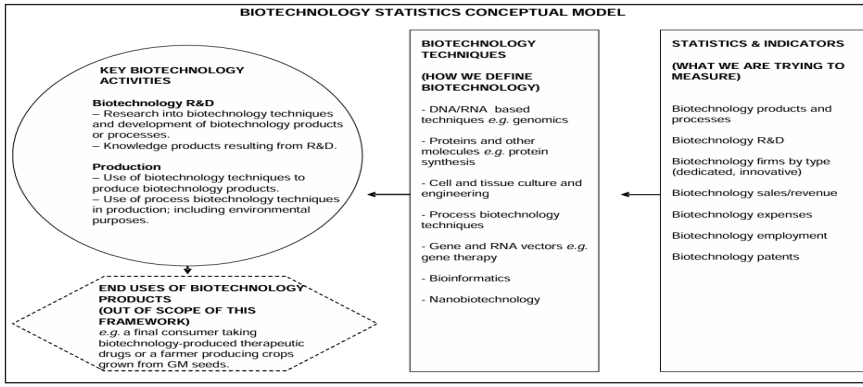
The rationale driving bioeconomy transition in Southeast Asia is said to flow from pushing its industry to make use of the large quantities of biowaste generated (Wang, et al., 2022). Meanwhile, boosting economic development through playing industrial catch up with the Global North using biotechnology has been termed as a primary motivation behind the bioeconomy strategies formulated by Argentina and Malaysia. South Africa at the same time has geared its bioeconomy strategy toward triggering a bioindustrial revolution that can boost the country's GDP. This broad vision is expected do translate to a growth in industries that can produce "bio-based services, products and innovations" (Department of Science and Technology, Republic of South Africa, 2013). In addition to encouraging bio entrepreneurs, this is expected to cascade into boosted growth for existing companies that can both produce and utilise these

services. In addition to job creation, East African Bioeconomy Strategy has looked at a technology-driven approach to improve the spillover effects from creating new agricultural value chains such as improving nutritional security through developing alternative protein production systems (Fortunate, 2022).

These divergent visions interpreting bioeconomy in light of respective capabilities has implications for policy making and implementation. Such divergences for instance have influenced how bioeconomy measurement frameworks are conceptualized. Measurement of bioeconomy is one area within the policy discourse which is still evolving. Both the USA and the EU documents point out the lack of maturity in bioeconomy monitoring and impact assessment tools. The Bureau of Economic Analysis (BEA), US Department of Commerce, the development of measurement mechanisms for bioeconomy as infeasible in the current context due to two reasons: firstly due to lack of consensus on bioeconomy definitions and secondly because of a scarcity of data, particularly in areas including biochemicals and bioplastics (Highfill & Chambers, 2023). In this regard the 2017 European Commission Report on the need to develop monitoring and assessment frameworks and the need to develop relevant indicators and scientific evidence for implementing a holistic assessment framework (European Commission, 2017, p. 88).

Meanwhile, the OECD, whose definition of identifies the formulation of indicators for bioindustry as the most difficult. The biotechnology compendium indicators (Figure 3) formulated by OECD's Working Party of National Experts on Science and Technology Indicators (NESTI) and the Working Party on Biotechnology presents indicators intended to capture how biotechnology contributes to economic output (Chaturvedi, 2005). The OECD defines bioeconomy as an "economic production model within which biotechnology contributes to a significant share of the output" (Figure 2). However, this may be inadequate for monitoring and measuring the contributions of bioeconomy guided by a bioresource or bioecological vision.

## Figure 2: OECD Biotechnology Compendium Indicators




***Source:*** OECD, 2005

Meanwhile, bioeconomy contributions within the EU policy framework are quantified using a methodology which estimates biomass content within bio-based products. Estimates are gathered from industry and biotechnology experts. These bio-based product shares are applied to Eurostat statistics to derive relative contribution of industrial sectors. Seemingly more comprehensive in nature, the EU's bioeconomy monitoring framework seeks to ensure that the economic social and environmental benefits flowing from bioeconomy activities are in alignment with sustainability goals.

The EU Bioeconomy Monitoring Framework is part of the European Union's efforts to track and support the development of its bioeconomy. This framework is designed to provide comprehensive, reliable, and up-to-date information on various aspects of the bioeconomy, ensuring that its economic, social, and environmental benefits are aligned with sustainability goals. It further has scope of measuring such impact across the value chain with indicators organized under four heads: Primary Production Systems, Ecosystem Condition, Secondary Production System and Waste and Circularity. The system is continuously updated to address gaps, such as climate change adaptation in forestry and fisheries or the social impacts of trade. It is further unique for including and interlinking Land and marine ecosystems & the services they provide

along with all primary sectors which use/produce bioresources and all sectors of the industry use bioresources and processes to yield products and services (European Commission, 2024).However, this framework excludes biopharma from measurement.

## Conclusion

Countries hailing from the Global North and the Global South alike have been attempting to anchor their approach to sustainable development and growth within the bioeconomy paradigm in the 21st Century. Bioeconomy visions of individual countries are primarily formulated in light of their respective capabilities and niche strengths. These strategies further prioritise circularity, sustainable consumption and environmental or biodiversity conservation while laying a dominant focus on leveraging economic opportunities that bioresources in combination with biotechnology and synthetic biology provide. The discourse on bioeconomy has also sought to lay an equal amount of emphasis on environmental concerns. This in turn renders bioeconomy as a production paradigm which allows room to balance between the two, while offering avenues to solve various challenges.

The High-level Principles on Bioeconomy which resulted out of the G20 Rio de Janeiro Summit in 2024 represents the views emanating from the Global South. From advocating for the sustainable use and conservation of biodiversity to underlining the activities within the bioeconomy to be driven by through safe, secure and responsible use of science, technology, innovation and traditional knowledge, the Brazilian Presidency effectively managed to reflect the concerns of the Global North as well as the Global South (G20 Initiative on Bioeconomy, 2024; Vijayakumar, 2024). While this represents a good start for initiating a multilateral conversation on bioeconomy, policy deliberations ought to outline various aspects including setting up sustainability standards and chart out the modalities for trade in bioresources to harness its full potential to the end of achieving climate goals.

Of particular importance is the need to build consensus on bioeconomy measurement indicators which can help track its contribution to overall economic growth and adherence to sustainable development goals.

In the current context, the definitional divergences have extended to measurement frameworks, rendering measurement in select areas complex. The OECD Biotechnology Compendium provides a strong basis for further work to be carried forward for measurement in bioindustry and biopharma sectors. Meanwhile, the EU Bioeconomy Measurement Framework offers a template for evolving monitoring mechanisms that can track sustainability and circularity across land and marine ecosystems. Herein, further probing is also required into Global South-specific measurement frameworks.

In Indian context, to emerge as a major contributor to the GDP of the country through high class achievement in technological superiorities in bioeconomy activities in biopharma sector, Indian Union Budget 2026–27, the government has rightly placed a significant emphasis on the biopharmaceutical sector, announcing the "Biopharma SHAKTI" initiative with a ₹10,000 crore outlay over five years to transform India into a global hub for biologics and biosimilars.

In the future, the bioeconomy is expected to be primarily driven by advances in areas including AI and synthetic biology. The opportunities and risks associated with the growing convergence between the two further needs to be understood and managed in order to make the global economy greener and more resilient. Cognizance of the implications of such a convergence in the policy sphere is a must for harnessing its potential. Among the countries assessed in this paper, India's strategy has been identified as unique due to its recognition of such a convergence.

As illustrated in this paper, the nation-states have defined and classified bioeconomy differently with some convergences and divergences across the board. Given this, there remains the challenge of carving out a common definition for bioeconomy as well as a common measurement framework at the global level. A concerted effort is required to address this challenge which needs to be reflective of the concerns of both the Global North and Global South. India, as one of the leading bioeconomies in the world, can play a leadership role towards this endeavour, while also emerging as a strong collective voice for the Global South to ensure that the bioeconomy-led paradigm leads to the inclusive, equitable and sustainable development.

## Endnote

[1] G20 Initiative on Bioeconomy meeting charts path to a sustainable bioeconomy https://www.dsti.gov.za/index.php/media-room/latest-news/4812-g20-initiative-on-bioeconomy-meeting-charts-path-to-a-sustainable-bioeconomy#:~:text=The%20third%20G20%20Initiative%20on,and%20long%2Dterm%20sustainability.%22

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## Annexure I

### India's Biotechnology Competitiveness Assessment

| Dimension | Components | Inputs |
|---|---|---|
| Enablers* | Human capital | No. of researchers/million population Quality of Research Institutions |
| | | Knowledge workers |
| | | Quality of Research Institutions |
| | Investment in R&D | R&D expenditure as a percentage of GDP |
| | | Government spending on R&D |
| | | Business and private (BERD) spending on R&D |
| | | Universities spending on R&D |
| | Safety & legal environment | IPR Protection |
| | | Efficiency of legal framework in settling disputes |
| | | Rule of Law |
| Facilitators** | Technology transfers | Industry-academia linkages on R&D |
| | | Barriers to tech transfer of publicly funded & supported research |
| | | State of cluster development |
| | | Patents filed in two or more offices |
| | Regulatory environment | Regulatory framework for biopharmaceuticals |
| | | Regulatory framework for bioagri |
| | | Regulatory quality |
| | Market incentives | Biopharmaceutical pricing and reimbursement policies |
| | | R&D tax incentives |
| | | Ease of doing business |

| | | |
|---|---|---|
| Performance*** | Clinical trials | Clinical trials |
| | | Clinical trials per million population to date |
| | | Clinical trial for biologics per million population to date |
| | Research output | Biotechnology triadic patenting, share of global average 1999-2013 |
| | | Scientific publications standardized for population |
| | | Quality of academic publications |
| | Biotechnology output | Biopharmaceutical product launches, percentage available in country within 5 years of global product launch |
| | | Biofuels production, percentage of global total |
| | | Biotechnology crops, hectares under cultivation, percentage of total |

*Factors necessary for overall growth and development in the industry

**Advanced factors that govern the long-term sustainability and profitability of the biotech industry

***Output indicators of the biotech industry

***Source*:** BIRAC & IFC. (2019). Assessment of Indian biotechnology landscape: An international perspective. Retrieved from Institute for Competitiveness: https://www.competitiveness.in/assessment-of-indian-biotechnology-landscape/#:~:text=The%20study%20analyses%20the%20Indian,%24100%20billion%20industry%20by%202025

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