Managing Emerging Disruptive Threats of Synthetic Biology

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Summary

Biology is the most powerful designing and manufacturing technology on the planet. A new stream of science called Synthetic Biology is further revolutionising it by redesigning organisms using the power of computing. Emerging trends in bio-design and generative design are set to alter the health, agriculture and energy space based on innovative ideas with unintended consequences and enhanced asymmetric threats. The 21st century will not be about programming computers but biology. The uncertainties surrounding the development of this dual-use technology have the potential to put humanity at risk. This fact is acknowledged by the Annual Threat Assessment Report 2024 published by the US Department of Defense (DoD) in February 2024. The era of Moore's Law is ending, but biology's exponentials are just beginning.

Destabilising Effects of Disruptive Technology

The 2024 Annual Threat Assessment (ATA) of the *US Intelligence Community Report* published by the US Department of Defense (DoD) in February 2024 talks about a robust intelligence response, including a near-term focus on managing the challenges posed by the new technologies in the fields of AI and biotechnology[1]. The Report highlights the unintended consequences of Generative AI to both leaders and followers as it enters the industrial age. The new designs and discoveries could lead to rapid development in asymmetric threats. The world is moving fast, and we sit astride the most pervasive penetrative platforms of the planet being created out of the combination of ubiquitous connectivity of computing power and biotechnology. Crafting stability out of technological innovation in a fiercely competitive world seems elusive. The world, which is enduring endless conflict, is now besieged with destabilising prospects in the absence of a legal framework to arrest the unethical use of new-generation technology.

The idea of replacing brain power with machine power makes the future seem scary as it tries to unravel the neural network and genome modelling as part of a human augmentation project. It creates yet another vulnerability to the human existence of a “hackable human”. The COVID-19 contagion has shown the world how a biomaterial, if not handled well and with no monitoring mechanism, can spoil a century of economic development in months. Toby Ord, in his book *The Precipice*, has quantified the probability of existential risks from future technologies as being roughly 100 times larger than the natural risk[2] (refer to Table 1).

Table 1: Existential Risk Landscape and Probabilities[3]

Natural Risk	Probability in the Next 100 Years	Manmade Risk	Probability in the Next 100 Years
Climate Change	1 in 1000	Nuclear War	1 in 1000
Naturally arising Pandemic	1 in 10,000	Engineered Pandemic	1 in 30
Environmental Damage	1 in 1,000	Unaligned AI.	1 in 10
Super Volcanic Eruptions	1 in 10,000	Unforeseen Anthropogenic Risks	1 in 30

Understanding Synthetic Biology

In 1952, the first X-ray picture of double helix DNA captured by Rosalind Franklin showed it as a twisted ladder of paired "letters" made up of molecular code in terms of A's, T's, C's, and G's, unlike the binary computer code of 0's and 1's. It implied that someday, it would be possible to read and write these codes.[4] In 1971, Paul Berg's breakthrough gene-splicing experiment was followed by the development of recombinant-DNA (rDNA) technology in 1973 by Herbert W. Boyer and Stanley N. Cohen. This technology aimed at artificially introducing genetic material from one organism into the genome of another and then replicating it. Despite the controversy surrounding the public fear of cloning, it prompted the mushrooming of commercial startups to capitalise on Boyer and Cohen's new rDNA technology. It was at this time that the IT companies were also emerging. Bill Gates and Steve Jobs, revolutionised information technology by packing greater computing power with every new product launch. From bits to qubits, the advent of quantum computing has exponentially added wings to the tools for DNA writing. The physical-to-digital-to-physical (PDP) loop based on high-performance computing, natural language processing and analytics, cognitive technologies, advanced materials, and augmented reality have enabled the simulated testing of predictive models. It is redefining the physical and digital technologies.

Steve Jobs, while undergoing treatment for pancreatic cancer, once remarked that the biggest innovations of the 21st century lie at the intersection of biology and technology.[5] Synthetic biology came into being as a multidisciplinary field at the dawn of the 21st century. The combination of principles from biology, engineering, and computer sciences is used to design and manufacture new biological systems or redesign existing ones for specific purposes or with new abilities.

Key techniques in synthetic biology include the synthesis of artificial genetic pathways called DNA synthesis, targeted genome editing (e.g., CRISPR-Cas9), DNA printing that allows long pieces of DNA to be written from scratch and metabolic engineering. However, this field is evolving at a frantic pace, and challenges remain in creating a web of registries of different bio-labs, standardised rules and models to understand the root structure. The software standards are also different. The complex nature of data interpretation needs a different type of software code rather than following the simple data table design. More importantly, it requires better visualisation tools and the ability to debug and redesign.

As synthetic biology has applications across various fields, including medicine, it holds the potential to address pressing challenges related to sustainable development. The ecosystem requirement to support this niche bio-technological field is humungous and needs large capital investment and governmental support. The cost of reading DNA has fallen more than a million-fold since the completion of the Human Genome Project twenty years ago. An interesting thing being talked about is that the 21st century will not be about programming computers but biology. A new law like the Moore's Law is under scripting as the exponential explosion in quantum computing and the bio-engineering world is set to revolutionise life processes.

Threats from Synthetic Biology

The design-build-test simulation models are maturing to such an extent that the artificially rearranged genetic elements built from DNA based on molecular code can be introduced into a living organism. These recreated micro-organisms can, in theory, do many of the same things that industrial processes can do, i.e., to convert sets of human needs into a physical object that fulfils those needs. These new DNA act as an additional "programme" that can harness the machinery in the micro-organisms like bacteria to make new fuels, therapeutics, biodegradable materials, or even biosensors. While it may take some time for these products and processes to be commercially available, an entire ecosystem of companies in the leading nations across the globe is working to revolutionise the material world.

A NATO report about the Bio and Human Enhancement Technologies (BHET) horizon 2023-2043, provides a glimpse of how synthetic biology and associated technology will impact humanity (refer to Table 2).

Table 2: Bio and Human Enhancement Technologies (BHET) 2023-2043

Emerging & Disruptive Technology	Technology Focus Areas	Impact	Technology Readiness Level	Horizon
BioTech	Bio-engineering & Genetics	High	5-6	2030-2035
	Bio-informatics	High	7-8	2025-2030
	Bio-manufacturing	High	3-4	2030-2035
	Bio-sensors & Bio-electronics	High	3-4	2030-2035
	Cognitive Enhancement	Revolutionary	3-4	2035 or (+)
	Human-Machine Symbiosis	Revolutionary	3-4	2035 or (+)
	Physical Enhancement	High	5-6	2030-2035
	Social Enhancement	High	5-6	2030-2035

Hence, the following risks against the potential benefits of this powerful technology need examination:

- **Accidental or Deliberate Release:** Accidental or intentional release of engineered harmful or disruptive organisms from labs or production facilities poses risks to human health, agriculture, and ecosystems.
- **Environmental Impact:** The unintended environmental consequences of engineered organisms can disrupt natural ecosystems through horizontal gene transfer (where genes

are exchanged between organisms), or they can become invasive species.

- **New Arms Race**: Strategic stability is related to arms control agreements. The proliferation of nuclear and chemical weapon systems was controlled largely due to the inspection and verification model instituted in them. However, the COVID-19 threat has exposed biosecurity and highlighted the failure of Biological Warfare Conventions (BWC) in regulating biomaterials, which pose a grave threat to humanity. Similarly, nation-states, to draw a first-mover advantage, are reluctant to promote control regimes.

- **Proliferation Risks:** The dual-use system developed by State and private enterprises is fraught with the risk of proliferation. The "dark web" has emerged as an unregulated space where biological resources can be accessed and used for illegal purposes. *The Economist* article published on 25 April 2020 titled "Spore Wars", highlighted the concern that bioweapons similar to COVID-19 or toxicants like ricin could be procured through the dark web.[6]

- **Unregulated Development**: In 2024, the Berkeley-based startup Profluent trained an AI to imagine new, never-before-seen CRISPR proteins — opening the door to gene editors with capabilities beyond what we have found in the wild. They are also making a brand new CRISPR system open source, so any scientist can now start leveraging an AI-designed gene editor to advance their research.[7] Profluent's new platform resembles ChatGPT for genetic technology.

- **Unethical Use:** The world worries that synthetic biology could be used for unethical purposes in the hands of non-state actors or lone wolves by creating or proliferating harmful engineered life.

- **Lack of Knowledge:** Synthetic biology is a relatively new field, and predictive modelling is not yet mature enough to fully understand the potential risks of engineering organisms. This lack of knowledge makes it difficult to assess and mitigate risks.

The dual-use nature of Synthetic Biology innovations has brought together individuals, companies, and institutions of governance in a collaborative and competitive mode. The participation of State and non-State groups has added a new security threat that has the prospect of altering the balance of power. The probability of incentivising risk-taking by State or non-State groups due to strategic instability needs to be factored-in while formulating an international security framework. Countries like the US, China and Russia are trying to increase the strategic space of the contest. Biomaterials are being developed as a non-nuclear deterrent as it is being perceived as the new strategic high ground by these countries. COVID-19 has demonstrated a threat to governments when societal cohesion is put at risk. China, as a consummate practitioner of grey zone contest, has already made deep inroads in this technology.

Brief Analysis of Biosecurity Regulations of Leading Countries

How to balance the healthy development of biotechnology and biosafety issues has become a challenge not only for the UN Biological Weapons Convention (BWC) but also for advanced countries that are heavily invested in synthetic biology. All leading countries around the world have attached significant priority to biosecurity issues, primarily after COVID-19. A brief look at the biosecurity regulations of leading countries like China, the US, NATO and Russia shows the importance and priorities being given to the field of biotechnology.

China

- In October 2019, China wanted to bring legislation on biosecurity, but COVID-19 delayed it.[8] In February 2020, during the onset of COVID-19, Xi Jinping called for strengthening the system and capacity building of epidemic prevention and control and scientific research on public health. He emphasised concentrating nationwide resources to double down on key and core technology research and urged breakthroughs in developing high-end medical equipment to accelerate fixing the country's "weak link" in this sector.[9] Finally, on 21 April 2021, the Act was passed by the 22nd Session of the Standing Committee of the 13th National People's Congress of China.

- The Biosecurity Law is divided into ten chapters, giving general requirements and specific management requirements for different biosecurity issues like the security of biotechnology laboratories, human genetic and biological resources, biosecurity capacity building, prevention of bio-terrorism and threats and legal liabilities with punitive measures. It lists 11 basic systems to be employed by the State Council and military based on the charter. These are: (a) establishing a National Biosecurity Work Coordination Mechanism (NBWCM) for biosecurity coordination, (2) NBWCM will be staffed by departments of health, agriculture and rural affairs, science and technology, and foreign affairs of the State Council, and relevant military organs, (3) biosecurity catalogue and list system, (4) biosecurity standard system, (5) biosecurity information release and media reporting mechanism, (6) emergency reform system, (7) information and source tracing system, (8) national access system to screen first-time entry of animals, plants and high-risk biological agents, (9) response system for major overseas biosecurity incidents, (10) biosecurity supervision and inspection by professionals and (11) conduct biosecurity risk investigations and assessments.[10] For Xi and the PLA, this is an idea of strengthening the defence in depth and creating a non-nuclear deterrent.

The US and NATO

The US Departments of Homeland Security (DHS) and Commerce work with the White House Office of Science & Technology (S&T) Policy to deploy countermeasures equipment for the protection of life, health, property, and commerce. It released the *National Strategy for Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE) Standards*, incorporating the federal vision and goals for the coordination, prioritisation, establishment, and implementation of CBRNE equipment standards by 2020[11]. The US S&T Directorate's focus areas in biotechnology remain two-fold: firstly, to monitor the worldwide biotechnological developments in life sciences and understand new opportunities that the US adversaries may misappropriate for offensive use and how the US can harvest them for defensive use. Secondly, to strengthen Homeland Security and Department of Commerce capabilities for quick detection and identification of hazardous biomaterials.[12]

The *2023 Biodefense Posture Review* by the US Department of Defense (DoD) lays out the strategic approach to counter biological threats and improve preparedness for bio-incidents. It assesses the biothreat landscape through 2035. It clarifies biodefence missions, priorities, roles, responsibilities, authorities, and the capabilities needed to enable biodefence and how the DoD is addressing future biothreats by aligning its doctrine, role, structure, research and development and acquisition with the US 2022 National Biodefence Strategy (NBS). The Review acknowledges the threats posed by China, Russia, North Korea, Iran, and violent extremist organisations. Accidental and deliberate biological threats have been compounded by the advances in synthetic biology and peptide synthesis, which have made the development and use of biological agents as weapons easier and difficult to detect. It also lists measures to mitigate the threats (refer to Figure 1).

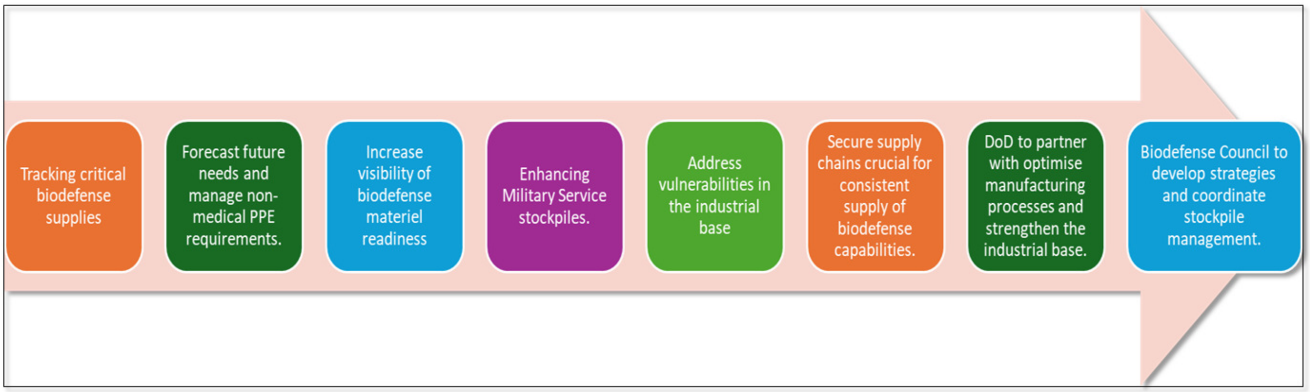

Figure 1: Measures to Mitigate Threats[13]

- The capabilities and threats that the field of synthetic biology poses are not trivial. According to NATO, the strategies and implementation of biotechnology and human enhancement technologies over the next few years will be the most challenging. The Pentagon and NATO are exploring the pattern of development of the new environment surrounding synthetic biology and other CBRNE issues.

- NATO's Allied Command Transformation is using a vast network of military and civil expertise in defence and academia to transform NATO's defensive capabilities for current and future security environments in the use of dual-use biotechnologies.[14]

- The US has established a National Biodefense Analysis and Countermeasures Center (NBACC) with fully accredited, state-of-the-art biosafety levels (BSL) 2, 3, and 4 lab facilities, spread across a 160,000 square-foot facility and 51,927 square feet of lab space. It houses two centres, the National Bioforensic Analysis Center (NBFAC), for technical analyses to support law enforcement investigations and the National Biological Threat Characterization Center that undertakes experiments and studies to examine biological vulnerabilities and hazards. Together, these Centres act as a national resource for risk mitigation against the malicious use of pathogens while supporting investigations, prosecutions and preventing biocrimes and bioterrorism. The BSL-4 accreditation allows NBACC to perform R&D on pathogens for which there are no vaccines or treatments available.

Russia

- The 2021 Russian Security Strategy signed by President Putin gives special impetus to the development of scientific and technological prowess of the Russian Federation. Out of 24 objectives laid out, three deal with efforts to increase scientific research in the field of biological, radiation and chemical safety. Placing Russia at leading positions in chemical, biological, medical, and pharmaceutical fields remains the focus. It also lists out high technologies like medical, biological, genetic engineering, artificial intelligence, big data processing, creation of new materials, cognitive technologies and supercomputer systems, to improve the Russian biodefence mechanism.[15] On the foreign affairs front, it lists the need for strategic stability by preventing non-proliferation mechanisms for weapons of mass destruction and calls for responsible behaviour mechanisms in the creation and use of biotechnology.[16]

- On 30 December 2020, Federal Law 492 on the Biological Safety of the Russian Federation was signed by President Putin to prevent biological threats due to the lack of monitoring of biological processes in microbiological laboratories while working with any infected material. The Law regulates the legal aspects surrounding biosafety issues. It lists measures to mitigate risks related to the spread of infections due to accidents, bioterrorist acts and sabotage. There are 17 stipulations in the Federal Law related to ensuring biosafety, biosafety activities, powers within the State's organs and local self-government organs in biosafety. The Law also covers the collection and preservation activities involving pathogenic micro-organisms and viruses, preventive measures at the laboratories and other intentional biological risks caused due to uncontrolled hazardous technical activities or terrorist acts. It lays out the government's information system about biosafety, the legal framework for violations, and the procedures for enforcement.[17]

India's Biotechnology Strategy

The Department of Biotechnology (DBT) is the nodal department under the Ministry of Science and Technology that deals with biotechnology in India, and is headed by a secretary-level officer. The department came into being in 1986. Initially, it had to encounter challenges related to research publication quality, lack of industry collaboration and problems in procuring equipment and reagents for the labs[18]. The DBT's mandate is ten-fold. Most of it relates to the development of business through R&D and academia-industry-international collaborations. It is also assigned the task of formulating Bio-Safety Guidelines related to the manufacture of cell-based vaccines.[19]

Over the past two decades, the DBT has brought in three Strategy Papers to invigorate the biotechnological ecosystem in India. The third Strategy Paper was to guide India post the COVID-19 pandemic between 2021 to 2025. It has been bullish on India's strength of a large scientific and engineering pool, a vibrant pharmaceutical industry with highest USFDA-approved cost-effective manufacturing outside the US, a large number of national research laboratories, centres of academic excellence in biosciences, biotechnology parks, a rich human gene pool, and growing numbers of biotech startups. However, it has listed certain areas that need to be addressed and regulated. These include contract research and clinical trials, the building of strong research partnerships, a requirement of large venture capital for high-risk sciences and quality assurance based on international standards.[20] The standards in this field are constantly evolving, but the vision document has failed to guide R&D

institutions in collaborating and creating critical standards and software essential to aggregate repository data.

The Strategy Paper also talks about developing a sustainable Indian model for biotechnologies to spur knowledge-based bioeconomy growth to the next level. It aims to place India among the top five global biomanufacturing hubs by 2025, with an aim to achieve a growth of US$ 150 billion.[21]

What has India done

India's proactive battle to combat COVID-19 was successfully spearheaded by the DBT and implemented through a dedicated Mission Implementation Unit at the Biotechnology Industry Research Assistance Council (BIRAC). It was complemented by the National Bio-Pharma Mission (NBM) and Ind-CEPI Mission, which facilitated the COVID-19 Vaccine Development Mission diagnostics and therapeutics efforts, enabling seven vaccine candidates by industry, eight candidates by academia and nine COVID-19 testing Hubs by creating biorepositories with more than 40,000 samples available to researchers and industry, development of therapeutics from natural products in partnership with Ministry of AYUSH supporting nearly 50 startups.[22]

India has taken baby steps to reinvigorate its research and innovation base. The 2023 National Research Foundation (NRF) Bill has sown the seed to promote and foster this culture in India's universities, colleges, research institutions, and R&D laboratories. The NRF is required to give high-level strategic direction to scientific research in the country by forging collaborations among the research institutions, industry, government departments, and academia, by creating interface mechanisms amongst participating industries and state governments besides the scientific and line ministries. The policy framework and regulatory processes have been created to encourage collaboration and increased spending by the industry on R&D.[23] The Prime Minister as the ex-officio President, and the two Union Ministers of Science and Technology and Education as the ex-officio Vice-Presidents, provide the requisite policy push to the wide-ranging scope of the NRF, as its Governing Board consists of eminent researchers and professionals across disciplines.

The NRF is the apex body under the Department of Science and Technology (DST). It is set up at a total estimated cost of Rs. 50,000 crores during five years (2023-28). For the DST, it is a big shot in the arm as its annual revised budgetary allocation has been only Rs 4,892 crores in FY 2023-24, which has been revised to around Rs 8,029 crores for FY 2024-25, a whopping 40 per cent increase. R&D, innovation, technology development and deployment have been the key concerns of the government. A sizable amount of Rs 596 crores was allocated for R&D and Rs 536 crores for innovation. However, Rs 200 crores each has only been utilised as per FY 2023-24 revised estimates (RE), pointing to a gap in policy implementation. In FY 2024-25, the R&D budget has been scaled down to Rs 291 crores while that for innovations and technology development has remained unchanged at Rs 536 crores. Out of the Rs 50,000 crores outlay for the NRF from 2023 to 2028, only Rs 2000 crores has been earmarked for FY 2024-25, and Rs 258 crores out of the allocated Rs 2000 crores, could be spent in FY 2023-24. However, it is encouraging to see that the National Mission on Interdisciplinary Cyber-Physical Systems has been given an impetus in the FY 2024-25 budget with an allocation of Rs 614 crores as against FY 2023-24 RE of Rs

435 crores, and the National Quantum Mission (NQM) has been granted Rs 477 crores as against Rs 5 crores in 2023-24.[24]

The DST initiated a focused programme, 'Cognitive Science Research Initiative (CSRI)', in 2008 to catalyse research in highly interdisciplinary areas of Cognitive Science and identified specific thrust areas in Cognitive Science, which include Foundations of Cognition Language and Cognition Computational Intelligence, Cognitive Psychology, Cognitive Neuroscience, and others. The CSRI encourages young and senior researchers to submit proposals in upcoming thrust areas of Cognitive Science.[25] However, no budgetary allocation has been made for this niche technology area. Though the Strategy Paper is more focused on evolving bioeconomy, it is silent on biosecurity.

India has done well by scaling up efforts. However, the scale and magnitude of research are getting exponentially vast and growing rapidly. The US and Chinese are moving fast to secure the areas related to standards and software architecture. In the coming decade, countries such as the US and China will lead a trillion-dollar Synthetic Biology industry that is set to disrupt energy, environment, health, agri-based, chemicals, and the food industry. The transformation is set to impact the production and supply chain, too, thus impacting the entire economy. BCG Henderson Institute analysis estimates that Synthetic Biology could affect almost 30 per cent of the global GDP, amounting to US$ 28 trillion by 2030.[26] The reported market value of this industry is more than US$ 17 billion, with an annual growth rate of 30 per cent.

What India Needs to Do

Geopolitical change, technological advancement, and concerns about the potential emergence of globally catastrophic biothreats have spurred a need to better understand future threats and collaboratively address them. The COVID-19 pandemic has elevated the value of advancing biosecurity. India needs to partner with countries like the US to capitalise on lessons learned to spur better government-to-government collaboration and continue focusing on investing in innovative technologies and strategies to improve national biosecurity.

The Government of India's support to the signing of the Biological Weapons Convention (BWC) was on the condition that the exemption related to biological agents or toxins was permitted for prophylactic, protective or other peaceful purposes only if it did not create a loophole regarding the production or retention of biological and toxin weapons.[27] The Indian Head of Mission during the 6th BWC Review Conference drew the attention of the world community to the advances in biotechnology, genetic engineering and life sciences. It was pointed out that the dual-use nature and easier access to these technologies have increased the danger of proliferation and hostile use.[28] India needs to relentlessly pursue the agenda for the inspection of BSL-3 and 4 laboratories through independent regulators to check on the production of new pathogens.

India needs to bring in biotechnology regulation to provide clarity and efficiency within industry, academia, research institutions, the Commerce Ministry and security agencies, while dealing with the complexities surrounding biotechnology products and their potential usage. Regulatory roles and responsibilities for oversight should be clearly spelt out by hosting a unified website. It will allow developers and researchers to work on compliance. A periodic review should be undertaken to align the research landscape with industrial production.

For India to secure and protect its bioeconomy, it needs to promote standards, establish metrics and network the repositories by building required privacy and safety protocols against threats of digital intrusion, manipulation and exfiltration. India will need to fortify its technological innovation and intellectual property rights.

Biotechnology funding remains crucial for this high-risk scientific mission. The public-private participation (PPP) model will provide space for research funding. However, to boost the bioeconomic environment, the DBT will need to publish periodic reports on biotechnology and biomanufacturers to further social goals related to health, agriculture, energy, and supply chain innovation. It must highlight areas where breakthrough is required to reduce the burden of disease and carbon footprint, improve nutrition among the masses and help in addressing food and energy security by supply chain management.

Data centres should be established to obtain inputs regarding biomass being generated from hospitals and monitoring the discharge of affluents. The national statistical records will help in better surveillance and data analysis for predictive preventive actions.

Biosecurity involves preventing and controlling major emerging infectious diseases and epidemics among animals and plants.[29] The Nuclear Threat Initiative (NTI) has correctly pointed out that countries and international institutions do not give biosecurity policies enough financial priority. India has paid the price for its negligence in implementing biosecurity and bio-surveillance. A cogent biosecurity policy must be evolved. The People's Liberation Army (PLA) of China has already vectored biological warfare in its concept of a non-nuclear deterrent programme. It called biotechnology 'the new strategic high ground for national defence', which will be driven by biomaterials and brain control weapons.[30] It is important that the office of the National Security Advisor be made the nodal office to coordinate this important national security situation.

Conclusion

The two dual-use sectors of biotechnology and communications have outpaced the regulations and increased the likelihood of health and economic surprise. The doctrinal precepts of security have been altered as the operating environment is borderless with seamless participation of State, non-State groups and individuals. The masking of biological weapons programmes inside a genuine legal vaccine-production facility or pharmaceutical plant is feasible. The industrial production and new supply chains of genomics aided by artificial intelligence (AI), supercomputers and civil-military fusion are going to make matters worse. The countries developing at the niche end of biotechnology may be looking for wealth generation using health emergency as an alibi. However, technology, even for peaceful purposes poses a grave risk to humanity if not monitored. The collapse of the barrier between digital and physical, synthetic and organic, is visible. In the absence of an intrusive inspection, monitoring and reporting system, India will need to firewall its biodefence system, as citizens' health remains a prime cause of concern for central, state and local governments.

The balance of power syndrome is still guiding the global economy. Strategic autonomy as part of India's foreign policy demands that the country be prepared to defend itself. The *Science Technology Vision 2035* published in 2015 by the DST lamented that India paid the price for its strategic autonomy by encountering global technology denial regimes. Technology sovereignty assumes importance as multinational corporations and patent offices will now play the future geopolitical game. Policies or strategies must be formulated to guide the contest.

India will need to strengthen the new BHET environment and capabilities in the areas of biowarfare and health, genetics and microbiology, bioengineering, bioinformatics, cognitive enhancement technologies and human-machine symbiosis in areas related to individual sensory and motor augmentation and social network predictive modelling, related to cognitive warfare campaigns. All these will need to be put through commercial considerations and the necessity of testing protocols and ELM (ethical, legal and moral) considerations. India will need to evolve proper frameworks to comprehend emerging opportunities and threats to establish a strategic edge.

The full potential of Synthetic Biology might not be realised immediately, but its gradual integration into various fields will be as transformative as the shift from vacuum tubes to transistors. The transistor created in 1947 by Bell Labs revolutionised technology gradually through a series of smaller developments that revealed its vast potential. The transistor was initially seen as an object of technical curiosity but soon it replaced vacuum tubes in radios, computers and a host of other electronic devices. Similarly, Synthetic Biology, through persistent experimentation, refinement and integration into existing technologies, will reshape the world economy. Wealth aggregation in the new millennium is mainly attributed to technology companies, and their competition will shape the future geopolitical contest. India needs a comprehensive national biosecurity policy to prevent disruptions to its economic growth. The Second World War ended with a nuclear explosion, and the next war will end with implosion. Armed Forces will need to carefully examine the fallout of the development of synthetic biology and plan the strategy and future force plan and structures accordingly. Structures follow strategy, and the window for its implementation is shortening with every passing day. The security threats posed by synthetic biology need a whole-of-a-nation approach.

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