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Asia and Pacific Research Center

Advances and Challenges in the Emerging Technology Field of "Synthetic Biology" in Australia, China and India

March 2024

Japan Science and Technology Agency

Established in April 2021, the Asia and Pacific Research Center (APRC) of the Japan Science and Technology Agency (JST) aims to contribute to building a foundation for innovation in Japan by expanding and deepening science and technology cooperation in the Asia-Pacific region based on the three pillars of research, information dissemination, and networking.
This report is compiled as part of a research that surveyed and analyzed science and technology innovation policies, research and development trends, and associated economic and social circumstances in the Asia-Pacific region. It is being made public on the APRC website and portal site to enable wide use by policymakers, associated researchers, and people with a strong interest in collaborating with the Asia-Pacific region; please see the websites below for more details.

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Executive Summary

It is obvious that synthetic biology is an important emerging technology that contributes both to economic growth and solutions to social issues, and is extremely beneficial to Japan and humanity, despite the risks associated with biosafety and other issues. Due to this, Japan's position in the Asia-Pacific Region, including the United States, which is said to be the world leader in the field in addition to Australia and India, and China, which is promoting large scale R&D investment, is extremely important. In this study, we analyzed the impact on Japan in terms of science and technology innovation, by comparing basic data from the U.S. with those from Australia, India, and China, which have strong scientific and technological capabilities in the Asia-Pacific region and show great potential in the field of synthetic biology, and then examined the direction that Japan should take regarding measures related to synthetic biology. The report also summarizes the direction that Japan should take with respect to policies related to synthetic biology and the possibilities for cooperation with these countries.

Science and technology policy and funding

Synthetic biology in Australia has grown from an individual, laboratory, or project-based effort, such as participation in iGEM in the late 2000s, to a large-scale network effort as announced in the National Innovation and Science Agenda (NISA) in December 2015. In light of this, knowledge-sharing and educational hubs are being actively formed by leveraging and strengthening the country's existing research infrastructure networks. In August of 2021, CSIRO (the Commonwealth Scientific and Industrial Research Organisation) published Australia's Synthetic Biology Roadmap, which predicted that the national market could grow to generate up to A$27 billion in annual revenue and supply 44,000 new jobs by 2040. In November of the same year, the Department of Home Affairs released its Critical Technology Supply Chain Principles, identifying synthetic biology as an emerging technology of strategic importance for supply chain security purposes. In addition, in December of the same year, the government's Critical Technology Policy Coordination Office (CTPCO) published the Blueprint for Critical Technologies and Action Plan as a strategy to protect and promote critical technologies. The Blueprint for Critical Technologies and the Action Plan, as a strategy to protect and promote critical technologies, designated nine technology areas, including synthetic biology, that are expected to increase in importance within the next 10 years. In connection to this, the Australian Defense Science and Technology Research Summit (ADSTAR) was held in July 2022, where government officials from the United States and the United Kingdom, along with representatives of other countries, discussed the risks of biotechnology. As a result, Australia has been comprehensively promoting synthetic biology in recent years, viewing it as an important field from the perspective of basic research, industrial deployment, and national defense and security.

China, setting a milestone at the 2008 Xiangshan Science Conference (XSSC), has been investing in R&D through collaboration between industry, academia, and government, establishing a journal named "Synthetic Biology Journal," and promoting biotechnology research, including synthetic biology, with the expectation that it will solve problems in the fields of medicine, agriculture, environmental restoration, and natural resource utilization and bring about economic and social development in the country. The government is also working to attract human resources from other countries and develop high-level human resources. In recent years, the "Fourteenth Five-Year Plan for National Economic and Social Development and the Outline of Distant Objectives for 2035," announced in 2021, mentions

synthetic biology technology with keywords such as "disruptive," "strategic needs," "frontier technology," and "key technology," and emphasizes the need for medium- to long-term development to become a world leader. Funding is also provided by the National Key Research Program of the Ministry of Science and Technology (MOST) for "synthetic biology" and "green biomanufacturing (绿色生物制造)," which aims to break away from fossil fuel dependence, as well as by the National Natural Science Foundation of China (NSFC) for its Major Research Programs. The NSFC's Critical Research Program also provides support for other types of research, from microbial applications to *in silico* metabolic networking.

India does not have many explicit policies focused on synthetic biology or funding that leans toward basic research, but the National Biotechnology Development Strategy 2021-2025 (NDBS2021-2025) announced in 2021 mentions human resource development in synthetic biology among its ambitions goal of contributing to a "knowledge and innovation-driven biotechnology economy" during the period it covers. In addition, in August 2022, the Ministry of Science and Technology announced a new program led by the Department of Biotechnology (DBT) - Biotechnology Industry Research Assistance Council (BIRAC) supporting interdisciplinary, high-quality, high-risk research and R&D called the "AMRIT GRAND CHALLENGE". The program's target areas include synthetic biology, along with health, agricultural biotechnology, and climate change. In addition, under the DBT's National Biotechnology Park Scheme, the central and state governments are working to stimulate biotechnology research in the country by establishing biotechnology parks, incubators, and pilot projects through public-private partnerships.

R&D Trends

Australia is actively collaborating with domestic universities and research institutions through hubs as well as with overseas collaborations; in September 2018, CSIRO established the Synthetic Biology Future Science Platform (SynBio FSP) to support innovation and create commercialization opportunities in the manufacturing, industrial biotechnology, environmental remediation, agriculture, biosecurity and healthcare industries and focuses on three programs: environment and biocontrol, chemicals and fibers, and symbionts and organelles. In addition, the Australian Research Council (ARC) Synthetic Biology COE (CoESB), headed by Macquarie University, is pioneering new approaches to microbial design, including for wine yeast, to develop custom-designed microbial populations and novel synthetic enzymes. The Australian Institute of Bioengineering and Nanotechnology (AIBN) at the University of Queensland opened a new integrated design environment facility called IDEA Bio (Integrated Design Environment for Advanced Biomanufacturing) at the end of 2021 for project design, including fermentation characterization, multi-omics characterization, and cellular design.

China's has a significant concentration of investment in Beijing, Shanghai, and the Greater Bay Area (Yuehua Bay Area), and among the many unique institutions, the Shenzhen Institute of Advanced Technology (SIAT), which was jointly established by the Chinese Academy of Sciences (providing personnel), the Shenzhen municipal government (providing land and facilities), and the Chinese University of Hong Kong (the proponent) and the Tianjin Institute of Industrial Biotechnology (TIB) of the Chinese Academy of Sciences are very active in the field. SIAT is actively engaged in industry-academia collaboration and has cooperative relationships with many companies such as BGI, HUAWEI, Tencent, etc. Although not limited to SIAT, it is also active in attracting talent. In 2017, Prof. Jay D. Keasling of the University of California, Berkeley, who succeeded in the biosynthesis of a special malaria drug (artemisinin) using yeast, opened an endowed research lab at SIAT as a visiting professor, aiming to promote the synthesis and commercialization of Chinese herbal medicine resources at that time. TIB-Tianjin University, established in 2012, was approved by the Ministry of Science and Technology on November 8, 2019, to build the National Synthetic Biology Innovation Center[1] (國家合成生物技術創新中心) in the Tianjin Airport Economic Area, and in the same year, TIB joined the Global BioFoundry Alliance (GBA) with the Shenzhen Institute of Advanced Technology (SIAT) Shenzhen Institute of Synthetic Biology, Chinese Academy of Sciences, to lead synthetic biology research in China. TIB's recent notable research achievements include the publication of a paper in Science on September 24, 2021, on the artificial starch assimilation pathway in collaboration with the Dalian Institute of Chemical Physics, Chinese Academy of Sciences (Dalian Institute of Chemical Physics), the, inorganic-catalyzed methanol reduction of carbon dioxide, and the world's first realization of artificial synthesis of carbon dioxide to starch, including enzymatic conversion of carbon dioxide to hexacharose, and was selected as one of the 10 Chinese domestic science and technology stories (organized by Science & Technology Daily) for the year 2021.

One of India's BIRAC flagship centers, the Center for Cellular and Molecular Platforms (C-CAMP), was established in 2009. It is located in Bangalore, Karnakatha, the Silicon Valley of India, which is also known as the center of innovation. The facility is equipped with the basic facilities necessary for drug discovery and biotechnology research, including high-resolution 3D X-ray microscopes, mass spectrometers, electron microscopes, and recombinant model organisms.

It is also part of the Bangalore Life Science Cluster (BLiSC) along with the National Center for Biological Sciences (NCBS), inStem, and Tata Institute of Genetics (TIGS), and has a strong presence by funding over 330 start-ups, the most successful of which is Bugworks, founded in 2014, which develops novel antibiotics that can act on Gram-negative and Gram-positive drug-resistant bacteria (Anti-microbial Resistance, AMR). Another successful global company that has taken advantage of the global trend toward precision medicine is Strand Life Sciences, a bioinformatics-based company that takes advantage of India's status as an IT powerhouse. While international collaboration in basic research is lacking in India compared to other countries, global development in the industrial field is active.

Implications for Japan

Synthetic biology has an extremely wide range of applications in the health and medical, food, environment and energy, and chemical industries, and is expected to drive economic growth in each of these countries. Although the U.S. and China are far ahead of the other countries in the basic and applied research phases, there are still many research issues in the field of synthetic biology that academia is working on, including whole-cell simulation, metabolic modeling - reverse synthetic pathway exploration (database and algorithm/modeling), and biohydrogen energy production, bio-bricks (parts from DNA to tissue) and their design research and biofoundry infrastructure technology (bio manufacturing) as mentioned by researchers at the Australia-Japan Synthetic Biology Workshop (held on March 16, 2022).

While there are countries such as China and India that lack international collaboration in research fields, the paper analysis in this survey suggests that collaboration with other countries in fields such as "codon optimization," "DNA data storage," "gene drives," and "bioprospecting" where Japan lacks advantage in terms of "number of papers" is a possible approach. In the fields of "global competition" and "artificial customization," Japan has a strong competitive

[1] Tentative translation by JST

edge.

In this field, where global competition is prominent and technological progress is rapid, as exemplified by the emergence of new technologies such as artificial custom cells, bio-3D printers, molecular robotics, and DNA data storage, Japan should focus on research platforms, activate joint research with top-level foreign institutions, and collaborate with other countries in academia to develop new technologies. In this field, where technological progress is rapid, it is expected that Japan will focus on research platforms, collaborate with top-level foreign institutions, and accelerate collaboration between academia and industry.

Table of Contents

1 Introduction

1.1 Defining Synthetic Biology

Synthetic biology is an interdisciplinary field that merges various disciplines such as biology, engineering, systems biology, bioinformatics, mathematics, chemistry, and computer science to artificially design life functions and construct artificial biological systems.

It is said that the term was first used by the French biologist Professor Stéphane Leduc around 1910[2]. However, modern synthetic biology is based on the idea proposed by the Polish geneticist Professor Wacław Szybalski in 1974 in response to advancements in analytical techniques. His definition involves devising new control elements, adding new modules to existing genomes, or constructing entirely new genomes[3].

In this research report, synthetic biology (or Engineering Biology) is defined as "a field of study that combines molecular biology and systems biology with engineering principles to design biological systems and biofactories," with the objective being "to create more sophisticated biological functions capable of addressing future challenges in areas such as energy generation, food production, optimization of industrial processes, and the diagnosis, prevention, and treatment of diseases.[4]"

Under the Biden administration, a report by the Congressional Research Service (CRS) titled "The Bioeconomy: A Primer" states that synthetic biology is a component of biotechnology[5].

- Biotechnology involves utilizing cellular and biomolecular processes to develop technologies and processes.
- Synthetic biology is one of the elements that constitutes biotechnology, specifically being the science of redesigning organisms for useful purposes by engineering them to have new abilities. Synthetic biology focuses not only on integrating into larger systems to solve specific problems but also on designing and constructing core components (such as parts of enzymes, genetic circuits, and metabolic pathways) that can be modeled, understood, and fine-tuned to meet specific performance criteria.
- The bioeconomy is economic activity driven by research and innovation in the life sciences and biotechnology, made possible through technical advancements in engineering and computer and information science.

2 S. Tirard. (2009) "Stephane Leduc (1853-1939), from medicine to synthetic biology", *Histoire des sciences medicales,* 43(1):67-72

3 W. Szybalski. (1974) "In Vivo and in Vitro Initiation of Transcription", in A. Kohn and A. Shatkay (Eds.), *Control of Gene Expression*, pp. 23–24, and Discussion pp. 404–405. New York: Plenum Press.

4 According to the Thermo Fisher Scientific website on "Synthetic Biology": https://www.thermofisher.com/jp/ja/home/life-science/cloning/synthetic-biology.html

5 N. Chaudhary, et al. (2021) "mRNA vaccines for infectious diseases: principles, delivery and clinical translation", *Nat Rev Drug Discov*, p. 817–838

1.2 Background

(1) The Development of Synthetic Biology

The world is entering an era of synthetic biology, driven by advances in biotechnology and computational capabilities. Dr. Craig J. Venter, an American molecular biologist who succeeded in synthesizing the entire genome of the bacterium *Mycoplasma genitalium* in 2008, has stated that we are moving from being able to read genetic code to being able to write it.

The development of synthetic biology has been propelled by advancements in nucleic acid sequencing (reading), genome editing, microarrays, nucleic acid synthesis (writing), and single-cell manipulation technologies. As shown in Figure 1-1, the cost of human genome analysis, which required 10 billion yen in 2000, had decreased to about 60,000 yen by 2020, thanks to the development of next-generation sequencers and information processing technologies over the past 20 years since the Human Genome Project[6]. This has been a significant driving force for the advancement of synthetic biology.

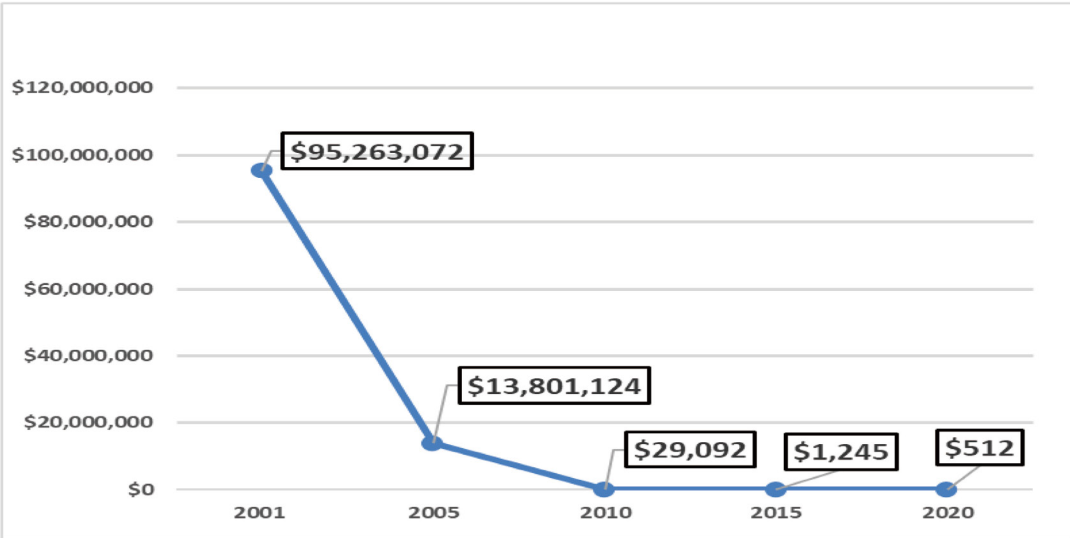


Figure 1-1 Cost of Human Genome Analysis

(Based on "The Cost of Sequencing a Human Genome[6]" by NHGRI, compiled by APRC)

Recent years have seen rapid advancements in applied research in crop breeding and medicine, thanks to the emergence of genome editing technologies like CRISPR-Cas9. The development[8] of synthetic RNA technologies for COVID-19 mRNA vaccines is also seen as a significant achievement in the field of synthetic biology. In addition, the establishment of technologies for synthesizing long-chain DNA of tens of thousands of base pairs and analyzing

[6] The Human Genome Project, planned by the American DOE and HHS, aimed to analyze the entire base sequence of the human genome. It was initiated in 1990, with a draft sequence published in 2000. The analysis was completed in 2003.

[7] NHGRI Cost per genome data (2021): https://www.genome.gov/about-genomics/fact-sheets/Sequencing-Human-Genome-cost

[8] Dr. Katalin Karikó and Dr. Drew Weissman faced the challenge of administered mRNA being recognized as a foreign substance in the body, which they overcame by replacing uridine with synthetically produced pseudouridine to evade immune functions, breaking through a major bottleneck.

their functional expression within cells is advancing research aimed at understanding the functions and principles of genomes. Examples of research that has greatly benefited from these technological innovations include the synthetic yeast genome project (Sc2.0) with 16 chromosomes reported in 2018 by Professor Jef D. Boeke of New York University, and the international project known as Genome Project-Write (GP-Write), started in 2016 in the United States, led by Professor George Church of Harvard University, aiming to understand the blueprint of life through the synthesis of human cell lines and genomes of organisms important for agriculture and public health.

Furthermore, dramatic improvements in computational power, the foundation for analysis, have rapidly advanced the fields of systems biology and high-throughput and automation technologies, allowing for the *in silico* reproduction and understanding of biological systems from molecular dynamics. With a deeper understanding of the blueprint of life and further advancements in these technologies, the manufacturing processes for biomolecules such as DNA could become standardized and automated in a manner similar to industrial assembly lines, envisioning a future where gene-targeted therapies, pharmaceuticals, and food production become more efficient, environmentally friendly, and available at lower costs.

Many of the technologies contributing to the development of synthetic biology were developed in the United States. America’s lead in the field of synthetic biology is generally attributed to the country’s continuous support for biotechnology research and development, regardless of scale, and a thriving ecosystem for investment in startups leading to commercialization.

(2) The Market for Synthetic Biology

In its future outlook for synthetic biology up to 2026, Markets and Markets’ Synthetic Biology Market report predicts that the Asia-Pacific region will experience the fastest growth, with key factors including an increase in synthetic biology research projects, enhanced collaboration with foreign companies in the Chinese market, and increased research and development budgets in the Asia-Pacific region. The market for synthetic biology spans tools (oligonucleotides / synthetic DNA, enzymes, etc.), technology development (genome engineering, sequencing, etc.), and applications (healthcare, pharmaceuticals, agriculture, etc.), with established companies (as seen in the STAR section in the top-right of Figure 1-2) like Thermo Fisher Scientific (US), Novozymes (Denmark), Merck KGaA (Germany), and Agilent Technologies (US), as well as startups centered in the United States, competing for market share. Established companies are actively expanding into China, including by establishing research and development departments. There are high expectations for mergers and acquisitions of high-tech startups and market expansion in the country. For instance, the German pharmaceutical company Merck has partnered with the Zhangjiang Group (Zhangjiang High-Tech Park) to open its largest Merck Innovation Hub in Zhangjiang Science City, a national-level key high-tech industrial development zone approved by China’s National Development and Reform Commission and the Ministry of Science and Technology, located in the Pudong district of Shanghai. This hub is driving new projects focused on the innovation ecosystem, healthcare, biotechnology, and electronics. Merck also has innovation centers in Shanghai and Guangzhou, Guangdong Province[9].

9 Merck website:https://www.merckgroup.com.cn/cn-zh/innovationhub_en.html

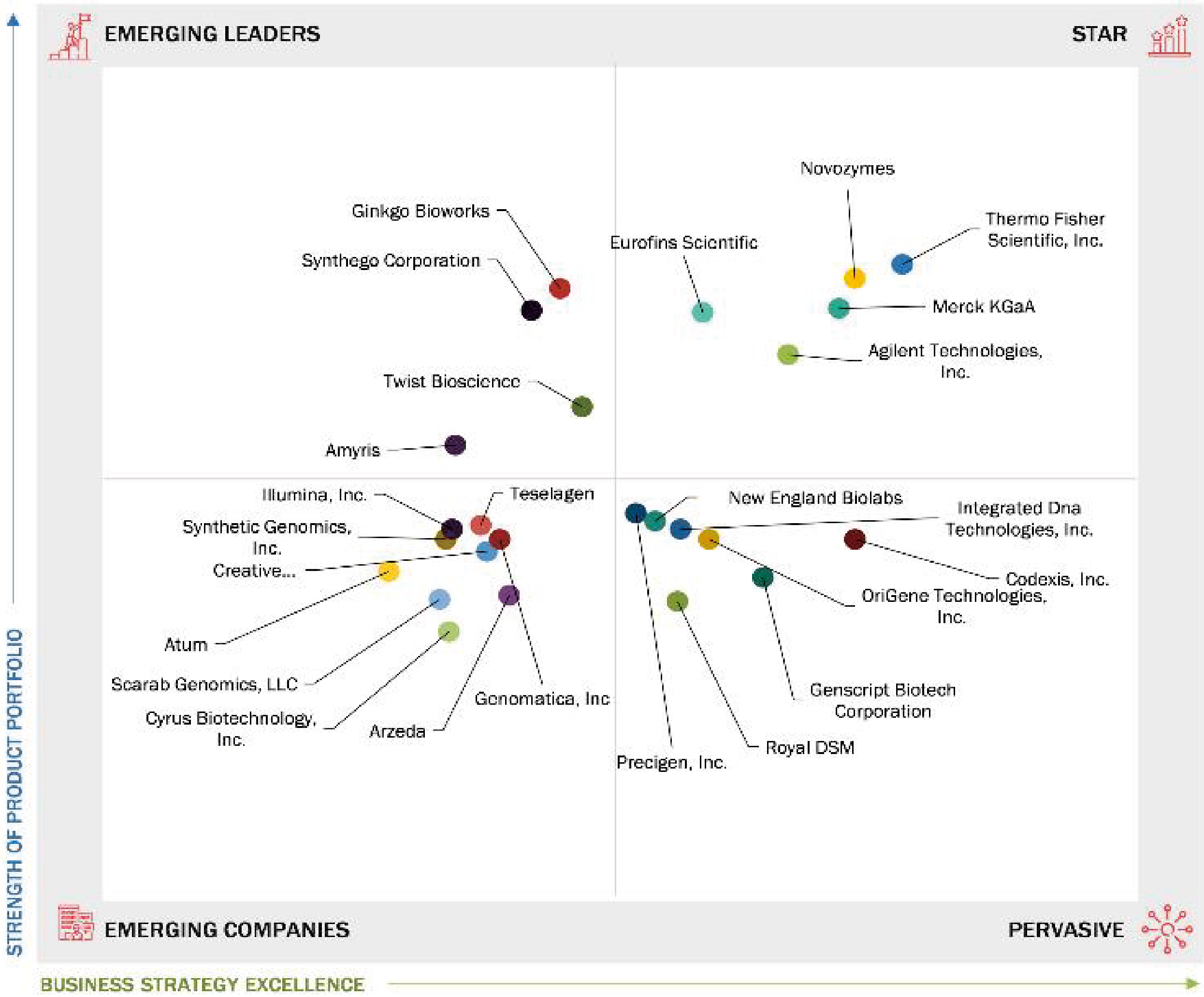


Figure 1-2 Synthetic Biology Market; Company Evaluation Map for 2020
(Published with permission from Markets and Markets "FIGURE 28 SYNTHETIC BIOLOGY MARKET: COMPANY EVALUATION QUADRANT, 2020")2020[10]

(3) The Risks Inherent in Synthetic Biology

The development and application of synthetic biology encompass issues and risks related to biosafety, biosecurity, and ethics. Synthetic biology also has a dual use in military applications. The Global Risks Report 2022 published by the World Economic Forum[11] lists examples of intentional/unintentional outcomes of technology such as AI, brain-computer interfaces, biotechnology, and quantum technologies under the category of technological advancements that could lead to negative legacies. One example of a related research outcome is the reconstruction of the 212kbp virus genome of horsepox—which had been considered difficult to clone due to issues surrounding its genome

10 The "STAR" companies in the top-right of In Figure 1-2 are highly evaluated for their robust product portfolios, high market share, broad application coverage, and global presence, indicating established companies that provide innovative tools and technologies. "EMERGING LEADERS" in the top-left are companies with innovative products and significant market presence but lack a strong growth strategy. "PERVASIVE" in the bottom-right are companies with strong business strategies and global distribution and supply capabilities but have a market share inferior to STAR companies. "EMERGING COMPANIES" in the bottom-left are companies offering niche products but are expected to grow.

11 WEF Global Risk Report 2022: https://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2022.pdf

hairpin structures and telomeres—by researchers at the University of Alberta, Canada, in 2018, by combining ten synthetic fragments[12]. Similar results are not limited to pathogens. For example, attempts to resurrect extinct animals (mammoths) led by Professor George Church, have garnered attention for their combination of positive and negative aspects. While it is difficult to halt or eliminate the advancement of technology, discussions on risk and governance structures, including the incorporation of protective and marker functions in the design process of genomes, are being held not only among governments but also within researcher communities like iGEM[13]. Additionally, the fact sheet from the Japan-US-Australia-India leaders' teleconference (Quad Summit), held on March 21, 2021, included a statement about facilitating cooperation to monitor trends and opportunities in the development of critical and emerging technologies, including biotechnology, through the Critical and Emerging Technology Working Group, which includes Japan, the United States, Australia, and India. Moreover, the joint statement from the Japan-US-Australia-India leaders' meeting on May 24, 2022, also mentioned ongoing discussions related to biotechnology.

1.3 Objectives of this Research Report

Although it entails risks such as biosafety, synthetic biology is an extremely useful significant emerging technology for both Japan and humanity and is internationally recognized as a key area for new industries. Major developed countries are actively promoting it as an essential technology for securing technological sovereignty (defined as possessing indispensable technologies within an industry and being independent from other countries' technologies). In this context, by gathering information on policies and research and development trends in Australia, China, and India, which can be said to be the leading countries in the field of synthetic biology in the Asia-Pacific region, this research aims to provide meaningful suggestions on the direction Japan country should take in terms of synthetic biology-related policies from the perspective of science and technology innovation, and the possibilities of cooperation with these countries. Relevant information from the United States[14], believed to be leading the world in this field, has also been surveyed for reference.

1.4 Research Methodology

Information collection and analysis in this research report primarily used the following three methods:

(1) Policy and Research and Development Trends (Chapter 2)

To assess trends in policies related to science and technology innovation and research and development related to synthetic biology in Australia, China, and India, an overview of trends in biotechnology and healthcare was acquired. If trends focused around synthetic biology were discovered in each country, those were investigated in depth. This

12 Ryan S., et al. (2018) "Construction of an Infectious Horsepox Virus Vaccine from Chemically Synthesized DNA Fragments", *PLOS ONE* 13, no. 1: https://doi.org/10.1371/journal.pone.0188453

13 iGEM (The International Genetically Engineered Machine competition) is the world's largest synthetic biology competition, held annually. It conceptualizes genes as blocks, combining them to imbue various functions into organisms. The most recent competition, iGEM2022, saw participation from over 5,000 people across 346 teams and was held in a hybrid format in Paris. https://blog.igem.org/

14 Protecting U.S. Technological Advantage (2022), National Academies of Sciences, Engineering, and Medicine. https://doi.org/10.17226/26647

involved desktop research on national initiatives in synthetic biology, major funding agencies, and research institutions in these countries.

For India, where no clear national initiatives in synthetic biology were uncovered (and there appears to be no flagship policy), the research report was conducted as a whole in the field of biotechnology, which includes this area. For the United States, its policies and research and development trends were noted as reference information and were considered important for fulfilling the objectives of this research report.

(2) Analysis of Scientific Papers and Patents (Chapter 3)

Clarivate's academic literature database Web of Science was used to collect data on papers. For data on patents, LexisNexis's TotalPatentOne (the world's largest patent database) was used. Data analysis was based on keywords specific to synthetic biology, a field within emerging biotechnologies.

(3) Summary (Chapter 4)

Based on the current situation of policies and research and development in Australia, China, and India (with the United States used as reference), this chapter summarizes the direction Japan should explore in synthetic biology-related policies from the perspective of innovations in science and technology, and the possibilities of building cooperative relationships in various fields with these countries.

(4) APPENDIX - Overview of Japan-Australia Workshop, etc.

To provide a reference for and to complement the investigation into policy and research and development in Chapter 2, the results from a workshop attended by top researchers from Japan and Australia are included. This workshop was held on March 16, 2022, under the co-sponsorship of the Japan Science and Technology Agency (JST) Asia-Pacific Center for Research (APRC), in cooperation with JST's International Division, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Australian Government's Department of Industry, Science, Energy and Resources (DISER), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Australian Embassy in Japan. The workshop facilitated information collection and discussions and hearings on areas for cooperation between the two countries. It was chaired by Professor Akihiko Kondo (Vice President of Kobe University) from the Japanese side and Dr. Claudia Vickers (CSO of Provectus Algae Pty Ltd.) from the Australian side and saw more than 150 participants share research outcomes and the latest information on synthetic biology, with 14 speakers presenting.

Note: The exchange rates mentioned in this report are based on the rates at the end of March 2022 (TTS). The parentheses indicate the fiscal year of each country.

- Australian Dollar: 94 JPY/AUD (July to the following June)
- Indian Rupee: 1.78 JPY/INR (April to the following March)
- Chinese Yuan: 19 JPY/CNY (January to December)
- US Dollar: 123 JPY/USD (October to the following September)

2 Policy and Research and Development Trends

2.1 Australia

Australia’s total research and development investment, according to OECD statistics, was 35.602 billion Australian dollars (approximately 2.9532 trillion yen) in 2019, with a GDP ratio of 1.8% (2019 estimate)[15, 16]. Statistics from Universities Australia also show that the funding sources for research and development expenses include the government, state governments, and companies, totaling 35.6 billion Australian dollars (approximately 3.3464 trillion yen) in 2019/20. The government’s research and development expenditure for 2021/22 was 11.8 billion Australian dollars (approximately 1.1092 trillion yen), a decrease of 184 million Australian dollars (approximately 17.2 billion yen) from the previous year[17]. 31.5% of the total research and development expenses are allocated to the higher education sector. The government’s research and development budget for 2020/21 (estimated) was 10.647 billion Australian dollars (2019/20, 9.328 billion Australian dollars)[18].

It should be noted that not all university research and research infrastructure is funded by government expenditure, and reliance on income[19] from international students (tuition fees) was not considered sustainable given the impact of COVID-19, posing a challenge on how to bridge this gap.

Investment in the field of synthetic biology was over 80.7 million dollars in public funds (2016-2021, approximately 9.9261 billion yen) [20] and over 20 million dollars in private funds (fiscal year 2020, approximately 2.46 billion yen)[21], leading to the establishment of 10 startups. However, this is significantly smaller compared to the public funding of 1.4 billion dollars (2005-2015, approximately 172.2 billion yen) and private funding of 5.3 billion dollars (2018, approximately 651.9 billion yen) in the United States, which holds a market share of 33-39%, with 336 startups, and the United Kingdom’s public funding of 550 million dollars (2009-2016, approximately 67.6 billion yen) and private

15 OECD Main Science and Technology Indicators, https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB

16 Private company investment, although data is from 2017, is estimated to be 17.43 billion dollars, accounting for more than two-thirds. OECD, Gross domestic expenditure on R&D by sector of performance and source of funds, https://stats.oecd.org/Index.aspx?DataSetCode=GERD_SOF&_ga=2.235261765.556047645.1620879487-64687999.1620879487 (Accessed October 20, 2022)

17 Universities Australia “RESEARCH FUNDING”: https://www.universitiesaustralia.edu.au/policy-submissions/research-innovations/research-funding/ (Accessed October 6, 2022)

18 “Australian Government R&D programs and activities valued at over $100 million in 2021-22”, https://www.industry.gov.au/publications/science-research-and-innovation-sri-budget-tables

19 Tuition fees are said to cover 27% of university research costs. From “University research funding: a quick guide” https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp2122/Quick_Guides/UniversityResearchFunding (Accessed October 6, 2022)

20 Total public funding budgets for ARC CoESB (37 million dollars from ARC and NSW government), CSIRO Synbio Future Science Platform and BioFoundry (27.7 million dollars), NCRIS Biofoundry Capability (8.3 million dollars), Macquarie Biofoundry (2.5 million dollars), QUT Mackay Renewable Biocommodities Pilot Plant (5.2 million dollars). This budget does not include specific research project funding.

21 Includes seed investments in Provectus Algae (3.25 million dollars in October 2020) and Nourish Ingredients (11 million dollars in March).

funding of 910 million dollars (2018, approximately 111.9 billion yen), with 150 startups and a market share of 8-12%[22].

The federal government's science and technology policy includes "Australia's Science and Research Priorities" announced in 2015 and the "National Science Statement" in 2017. However, as mentioned later, they are expected to be updated following the change of government in July 2022, with the Albanese administration also focusing on "Putting science back into government" to formulate evidence-based policies.

Australia is famous for the discovery of *Helicobacter pylori* by Professor John Robin Warren and Professor Barry James Marshall of the University of Western Australia, who won the Nobel Prize in Physiology or Medicine in 2005. This research originated from Professor Warren's discovery of small, curved, previously unknown bacteria (*Helicobacter pylori*) in the stomach mucosa of patients with gastritis in 1979, reflecting the longevity of research in this field. Recently, Professor Edward C. Holmes of the University of Sydney, specializing in virus research, was one of the first to announce the genetic sequence of the virus causing COVID-19 (SARS-CoV-2) to the world, along with China[23]. This discovery contributed to the acceleration of preclinical and clinical trials for vaccine candidates in Australia.

The contribution of the medical technology, biotechnology, and pharmaceutical sectors to the overall economy of Australia was $5.5 billion AUD (Gross Value Added: GVA basis, approximately 517 billion yen) in 2021, an increase of $300 million AUD (approximately 28.2 billion yen) compared to 2019[24]. Employment increased by a total of 5,000 people over two years. However, supply chain challenges meant that exports decreased by 18% over the same period. Nevertheless, based on these solid efforts to date, there is a prospect of growth to $7.6 billion AUD (approximately 714.4 billion yen) by 2025, creating an additional 3,000 jobs. Various plans have been formulated by government agencies, public institutions such as universities, and the industry for research and development and industrial cultivation of biotechnology, with specific financial and institutional support systems being introduced to implement them.

Synthetic biology in Australia has grown from an individual, laboratory, or project-based effort, such as participation in iGEM in the late 2000s, to a large-scale network effort as announced in the National Innovation and Science Agenda (NISA)[25] in December 2015. In light of this, knowledge-sharing and educational hubs are being actively formed by leveraging and strengthening the country's existing research infrastructure networks.

In August of 2021, the CSIRO (the Commonwealth Scientific and Industrial Research Organisation) published Australia's Synthetic Biology Roadmap, which predicted that the national market could grow to generate up to $27 billion AUD (approximately 2.538 trillion yen) in annual revenue and supply 44,000 new jobs by 2040. In November of the same year, the Department of Home Affairs released its Critical Technology Supply Chain Principles, identifying synthetic biology as an emerging technology of strategic importance for supply chain security purposes[26]. Furthermore, in December, the government's Critical Technology Policy Coordination Office (CTPCO) published

22 CSIRO "A National Synthetic Biology Roadmap", 2021

23 Fan Wu et. al. (2020) "A new coronavirus associated with human respiratory disease in China", *Nature*, Vol. 579

24 MTPConnect. (2022) "Medical Technology, Biotechnology and Pharmaceutical Sector Competitiveness Plan", MedTech and Pharma Growth Centre, p5, https://www.mtpconnect.org.au/images/2022_MTPConnect_SectorCompetitivenessPlan.pdf (Accessed October 20, 2022)

25 As mentioned later, NISA outlines a future vision for Australia. It states that to create high-wage employment and new waves of economic prosperity, new ideas in the fields of innovation and science must be adopted to create new drivers of growth. It places focus on (1) culture and capital, (2) collaboration, (3) talent and skills, and (4) government as an exemplar.

26 Commonwealth of Australia 2021 "Critical Technology Supply Chain Principles"

the Blueprint for Critical Technologies and Action Plan as a strategy to protect and promote critical technologies, designated nine technology areas, including synthetic biology, that are expected to increase in importance within the next 10 years. (5G/6G, AI, cybersecurity, genomics and genetic engineering (including synthetic biology), quantum technologies, etc.).

As a result, Australia has been comprehensively promoting synthetic biology, viewing it as an important field from the perspective of basic research, industrial deployment, and national defense and security. This chapter summarizes major policies, research and development, and industry trends in the field of biotechnology, including synthetic biology, in Australia.

2.1.1 Government Organizations and Systems

Following the federal election in May 2022, Anthony Albanese, leader of the Labor Party, became the next Prime Minister, and on June 23, the new government’s organization was announced, with the new government officially coming into power on July 1.

Examining the history of Australia’s science and technology innovation policies, the Office of the Chief Scientist was established under the Department of Industry, Science and Resources in 1989 to provide authoritative and independent scientific advice on the government’s science and technology priorities. Additionally, in 2014, the National Science and Technology Council was established as an advisory body to the Prime Minister and related ministers on significant issues related to science and technology, with the Prime Minister as chair and participation from the Chief Scientist. The main organizations and institutions related to synthetic biology under the Albanese administration are outlined in Figure 2-1.

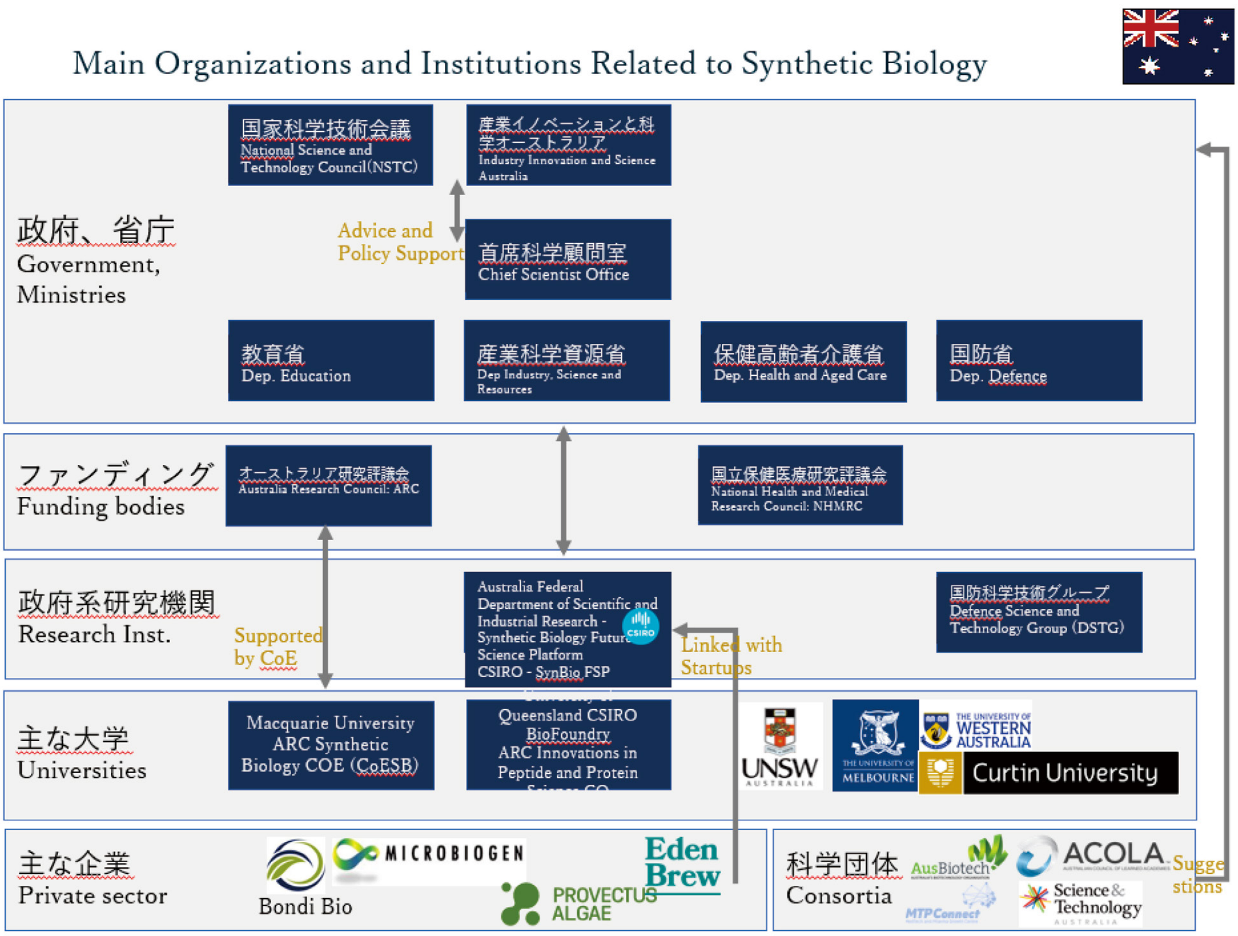


Figure 2-1 Main Organizations and Institutions Related to Synthetic Biology in Australia

The Chief Scientist is a full-time position, also serving as the chair of the National Research Infrastructure Advisory Group, the Australian Climate Change Science Framework Coordination Group, and a member of other significant domestic and international science and technology-related meetings. Reports prepared by the Office of the Chief Scientist are submitted to the Minister for Industry and Science after consultation with the Prime Minister and related ministers. The current Chief Scientist, the ninth in the role, appointed in August 2018, is Dr. Cathy Foley[27], who has achieved significant accomplishments in semiconductor electronics research at the CSIRO.

The National Science and Technology Council is also an institution that advises the Prime Minister and related ministers on important science and technology issues. Within the council, the Prime Minister serves as chair, and the science and technology-related ministers as vice-chair. The Chief Scientist acts as the Executive Officer, and the head of the CSIRO is a permanent member. The structure also includes six scientific expert members . The council’s tasks are to address long-term and emerging issues, policy priorities in science and technology, the science and technology system, goals set by the National Science Statement (mentioned later), and other requests from the Prime Minister and related ministers. It typically holds four meetings annually. Furthermore, as part of the advisory process from the scientific community to the parliament and members of parliament, various platforms such as the functions of the

27 Dr Cathy Foley, Australia’s Chief Scientist: https://www.chiefscientist.gov.au/DrCathyFoley (Accessed October 6, 2022)

Chief Scientist, direct dialogs with researchers, events like Science Meets Parliament[28], and the Australian Council of Learned Academies (ACOLA) have been established.

As shown in the schematic diagram in Figure 2-1, the differences compared to the Scott Morrison administration include the renaming of the "Department of Education and Training" to the "Department of Education," the "Department of Health" to the "Department of Health and Aged Care," the "Department of Industry, Science, Energy and Resources" to the "Department of Industry, Science and Resources (DISR)," and the establishment of the "Department of Climate Change, Energy, the Environment, and Water."[29] Additionally, the Defence Science and Technology Group (DSTG) under the Department of Defence is a research institution that uses science and technology to protect Australia and its interests. It is one of Australia's largest organizations, with about 2,200 staff, including scientists, engineers, and IT specialists, led by the Chief Defence Scientist, providing expert and impartial advice and innovative solutions for defense and national security.

The main government research funding agencies related to science and technology innovation in Australia include two organizations that provide grants based on researchers' scientific curiosity using a bottom-up approach: the Australian Research Council (ARC) under the jurisdiction of the Department of Education, and the National Health and Medical Research Council (NHMRC) under the Department of Health and Aged Care.

However, there are also examples of top-down funding, including grants for research addressing socio-economic and environmental challenges that are available from various departments and related agencies, including the Cooperative Research Centres (CRC) Grant Program from DISR[30]. Of relevance, a recent challenge in science and technology innovation is the recognition of research and development outcomes based on academic paper rankings and other metrics, which don't reach commercialization or product development[31].

2.1.2 Major Policies and Key Issues

This section reviews major policies related to synthetic biology by the Australian government and related agencies in recent years.

(1) National Innovation and Science Agenda (NISA)[32]

NISA, announced in November 2015, aims to expand financial support for entrepreneurs, encourage risk-taking and enhance public research, broaden cooperation between industry and research institutions to contribute to solving

28 Science Meets Parliament is a networking event between federal members of parliament and science and technology stakeholders that started in 1999. A lecture by Professor Katalin Karikó is scheduled for March 2023. The organizer of this event is Science & Technology Australia (formerly: Federation of Australian Scientific and Technological Societies (FASTS)), an organization formed by multiple science and technology-related bodies.
https://scienceandtechnologyaustralia.org.au/what-we-do/science-meets-parliament/science-meets-parliament-2023/

29 Administrative Arrangements Order made on 23 June 2022,
https://www.pmc.gov.au/sites/default/files/publications/administrative-arrangements-order-23-June-2022.pdf (Accessed October 6, 2022)

30 "Backing research centres to boost economic output 13 January 2023",
https://www.minister.industry.gov.au/ministers/husic/media-releases/backing-research-centres-boost-economic-output

31 Australian Parliament Tim Brennan, "Parliamentary Library Briefing Book - Science and research", June 2022
https://www.aph.gov.au/About_Parliament/Parliamentary_departments/Parliamentary_Library/pubs/BriefingBook47p/ScienceResearch

32 National Innovation and Science Agenda report:
https://www.industry.gov.au/publications/national-innovation-and-science-agenda-report (Accessed October 2, 2022)

global challenges and create jobs, attract world-class researchers, and capture innovations that lead to industrial development. The plan provides an investment of 1.1 billion Australian dollars (approximately 103.4 billion yen) over the four years following its announcement. In relation to biotechnology, this agenda included a proposal to establish a Biomedical Translation Fund (BTF) to commercialize promising discoveries. The government contributed 250 million Australian dollars, and private companies provided 251.25 million Australian dollars (approximately 23.6 billion yen) to the fund, which operates at a total scale of 501.25 million Australian dollars (approximately 47.1 billion yen)[33].

(2) 2015 National Science and Research Priorities[34]

The Australian government (at time of writing: the Department of Industry, Science, and Resources) identified nine priority areas in the 2015 National Science and Research Priorities, including food, soil and water, health, and manufacturing technologies related to biotechnology. These priorities form the basic support target for ARC funding. The Australian government also announced on September 27, 2022, that it has started a review led by the Chief Scientist with a task force in the Department of Industry, Science, and Resources, aiming to complete an update to the priorities within the next 12 months[35].

Items (1) and (2) were established prior to facing urgent issues such as climate change, infectious disease countermeasures, and emerging critical technologies. The Albanese government will hold discussions with the scientific and industrial communities in response to these challenges. Based upon the results of this dialog there will be a review of priorities led by the Department of Industry, Science, Energy, and Resources over one year, starting in 2022.

(3) 2017 National Science Statement[36]

The National Science Statement, formulated in 2017, sets long-term national goals and aims to provide guidance to the government. Its main content includes strengthening Australia's science system and providing guidelines for government investment and policy decisions.

The statement identifies challenges such as only 4.8% of corporate investment going towards cooperation with universities or publicly supported institutions, and weaknesses in STEM education, making it difficult to supply a skilled workforce. The statement, therefore, outlines guidelines such as basing economic development on science, focusing investment in scientific research on advanced research, stabilizing and making predictable support for research, promoting and supporting interdisciplinary, industrial, and international cooperation, and maximizing opportunities for all Australians to engage in science.

33 Biomedical Translation Fund: https://www.bulletpoint.com.au/biomedical-translation-fund/ (Accessed October 2, 2022)

34 Science and Research Priorities: https://www.arc.gov.au/funding-research/apply-funding/grant-application/science-and-research-priorities (Accessed October 2, 2022)

35 Australian Government to revitalise our science priorities: https://www.industry.gov.au/news/australian-government-revitalise-our-science-priorities; https://www.industry.gov.au/sites/default/files/2022-09/revitalising-australias-science-priorities-terms-of-reference.pdf (Accessed October 6, 2022)

36 National Science Statement 2017: https://nicm.edu.au/__data/assets/pdf_file/0004/1233823/National-science-statement.pdf (Accessed October 6, 2022)

(4) Synthetic Biology in Australia: An outlook to 2030 [37]

In 2018, the Australian Council of Learned Academies (ACOLA) published a document titled Synthetic Biology in Australia: An outlook to 2030. The chief author was Professor Peter Gray, a fellow of the Australian Academy of Technological Sciences and Engineering and the inaugural director of the Australian Institute for Bioengineering and Nanotechnology (AIBN) at the University of Queensland. Although this document does not represent the government’s view, it involved many renowned experts from the Australian academies, such as Dr. Claudia Vickers (see Appendix), leading to the recommendation paper by the Office of the Chief Scientist mentioned in (5). The document highlights the following points.

- That Australia has a strong scientific foundation and advanced knowledge in agriculture, positioning it favorably in the field of synthetic biology.
- Through intensive and cooperative efforts, Australia can create internationally competitive new industries and protect the export base of its agriculture.
- Communicating the potential benefits and risks of synthetic biology to the public is extremely important.
- Australia’s regulatory system for technology related to genetic modification is one of the most effective and advanced in the world and revising it to reflect international trends is essential for the development of synthetic biology.
- Developing talent with knowledge in STEM and HASS (Humanities, Arts, Social Sciences), and building national infrastructure for international competitiveness is necessary.

(5) Occasional Paper: SYNTHETIC BIOLOGY[38]

Based on ACOLA’s document, the Office of the Chief Scientist released a recommendation paper (occasional paper) on August 5, 2020. While it largely agrees with ACOLA’s document, it states that Australia has research capabilities and expertise in the field of synthetic biology, a regulatory environment, access to the Asian market, and a strong agriculture-related industry, enabling it to leverage the opportunities synthetic biology offers. The paper lists the following four challenges Australia should address:

- [Bridging the Gap Between Science and Industry] Current synthetic biology tools cannot predict the outcomes of circuits made by combining multiple synthetic parts. Therefore, directed evolution method— which won the Nobel Prize in Chemistry in 2018—and modularization of parts are important approaches. The paper notes it is essential to prepare a large number of interchangeable parts, much like LEGO® bricks. To address this need, the CSIRO is prioritizing the construction of a BioBricks library and has established the Synthetic Biology Future Science Platform to support industrial development.
- [Enhancing Skills and Knowledge] Australian universities and industry are particularly skilled in tool development, circuit design, protein engineering, and bioengineering, but there is a need to strengthen their technological foundation in genome design and artificial gene construction. To enable the applied development of synthetic biology, an interdisciplinary field, it is necessary to enhance the development of talent in IT, artificial intelligence, engineering, robotics, and machine learning, which are the basis for design, testing, and

37 Synthetic Biology in Australia: An outlook to 2030: https://acola.org/hs3-synthetic-biology-australia/

38 Clarissa Fraser, Peter Gray, Office of Australia’s Chief Scientist (2020) “Synthetic Biology Occasional Paper”: https://www.chiefscientist.gov.au/news-and-media/occasional-paper-synthetic-biology

manufacturing.

- [Infrastructure Investment and Construction] Commercial facilities are needed to transition research findings to large-scale production composed of products and components derived from synthetic biology. Over the past decade, support and investment for research and development in synthetic biology has expanded, and under the National Collaborative Research Infrastructure Strategy, facilities such as the National Biologics Facility and the Mackay Renewable Biocommodities Pilot Plant at Queensland University of Technology have been developed. Additionally, the New South Wales government has supported Macquarie University with 2.5 million Australian dollars (approximately 235 million yen) to establish a biofoundry (a genome foundry with automated DNA assembly and evaluation facilities)[39], and the CSIRO has partnered with the University of Queensland to establish a biofoundry.
- [Regulatory Framework for Risk Management] Predicting and assessing the potential risks synthetic biology may pose to human health, biosecurity, and the environment is crucial, necessitating a review of genetic technology and the regulatory framework.

(6) National Synthetic Biology Roadmap [40]

The National Synthetic Biology Roadmap released by the CSIRO in August 2021, based on ACOLA's documents and recommendations from the Chief Scientist's office, identifies the value of synthetic biology for Australia and outlines methods for accelerating the demonstration, expansion, and commercialization of applications.

Under predictions that synthetic biology will become a $700 billion industry globally by 2040 (approximately 65.8 trillion yen), Australia is positioned to become a competitive leader in the Asia-Pacific region by designating the period between 2021 to 25 as one of "Building capability and demonstrating commercial feasibility" 2025 to 30 as "Early commercial successes and establishing critical mass," and 2030 to 40 as the "Growth through scaling market-determined application priorities." This roadmap was jointly created based on input from over 140 individuals representing more than 60 organizations across government, industry, and research institutions.

(7) National Research Infrastructure Roadmap 2021[41]

The National Research Infrastructure Roadmap 2021, by the Department of Education, sets priorities for future investments in Australia's research infrastructure, with specific funding provided through the National Collaborative Research Infrastructure Strategy (NCRIS) program. Compiled by an Australian expert group led by Dr. Ziggy Switkowski, Chancellor of Royal Melbourne Institute of Technology (RMIT), it outlines the national research infrastructure needed over the next decade for maintaining Australia's excellence and innovation and addressing new challenges.

In the roadmap, synthetic biology is mentioned in the eighth recommendation as a research foundation for realizing

39 According to the National Synthetic Biology Roadmap, a biofoundry is defined as "A facility containing the resources, equipment, and software required for high-throughput engineering of DNA-encoded biological components and systems. Biofoundries conduct the Design-Build-Test and Learn stages of advanced bioengineering and synthetic biology research and development (R&D)"

40 CSIRO, "Australia's Synthetic Biology Roadmap," 2021. https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/future-industries/synthetic-biology-roadmap

41 Australian Government, Department of Education, "National Research Infrastructure": https://www.education.gov.au/national-research-infrastructure

the bioeconomy and as preparation for tackling future challenges, alongside digital infrastructure, environmental and climate research, and bridging studies. It highlights the need for a strong network that integrates various omics research and high-performance computing for synthetic biology research. However, it emphasizes the need for the formation of a strong network tailored to synthetic biology, functioning in conjunction with these elements, as a national infrastructure for research.

- The roadmap calls for biofoundries to streamline engineering processes foundational to synthetic biology research, enabling rapid product development across various biological systems and capacities.
- It also states that access to a variety of bioreactors for experimental research would be desirable.
- In addition, the roadmap states that efficiency and synergies must be maximized through integration and networking with other national research infrastructures and existing synthetic biology platforms, including international organizations.
- In the interdisciplinary field of synthetic biology, it states that virtual/physical support from experts familiar with various technologies is required.

(8) Biotechnology in Australia – Strategic Plan for Health and Medicine[42]

In March 2022, the government evolved the "Health and Medical Industry Growth Plan 2018" into the "Biotechnology in Australia – Strategic Plan for Health and Medicine." This plan aims for investment in the innovation ecosystem from basic research to application, particularly targeting the commercialization of medical products. The plan states that cooperation between governmental research institutes and groups such as the CSIRO, ANSTO[43], and the Defence Science and Technology Group will be vital. It establishes three pillars.

- Strategic investments in key areas will be made to support world-class research and development to promote industry-academia-government partnerships.
- The international competitiveness of research capabilities, processes, and infrastructure will be enhanced to ensure a high-quality and safe clinical development framework.
- Accelerating commercialization through manufacturing support for pharmaceutical and medical technology products and industry-academia-government partnerships.

This strategic plan is coordinated with the "Medical Products Roadmap under the Modern Manufacturing Strategy (MMS)"[44] announced by the Department of Industry, Science, Energy, and Resources (at the time) in October 2020, and aims to contribute to the biotechnology sector over the next decade with more than 8 billion Australian dollars (approximately 752 billion yen) in added value, over 1,400 related companies, over 80,000 supported employment positions, and more than 12 billion Australian dollars (approximately 1,128 trillion yen) in product exports through sustained growth in clinical trials.

42 Biotechnology in Australia: https://www.health.gov.au/sites/default/files/documents/2022/03/biotechnology-in-australia-strategic-plan-for-health-and-medicine.pdf

43 ANSTO's national deuteration facility contributes to the commercialization of mRNA products by mass-producing deuterated biomolecules for both biomedical and pharmaceutical research.

44 Modern Manufacturing Strategy (MMS): Formulated by the Department of Industry, Science, Resources, and Energy in October 2020, this strategy supports Australian manufacturing with a total investment of 1.3 billion Australian dollars (now increased by 146 million Australian dollars). Medical products are one of the six priority areas along with food, recycling/clean energy, defense, and space, etc. https://www.industry.gov.au/news/modern-manufacturing-initiative-and-national-manufacturing-priorities-announced(Accessed October 1, 2022)

The biotechnology sector is separated into different colors and includes medical products (pharmaceuticals, red), agricultural bio (green), industrial & energy (gray), and marine (blue) sectors. The importance of vaccine technology, diagnostic technology, and therapeutic technology in synthetic biology is highlighted, with the "National Synthetic Biology Roadmap" suggesting methods for demonstration, expansion, and commercialization acceleration. This strategic plan is reviewed every five years, and priorities are redefined every two years.

In relation to this policy, the Australian Defence Science, Technology and Research Summit 2022 (ADSTAR 2022) was held in Sydney from July 20 to 22, 2022, hosted by the Defence Science and Technology Group (on behalf of the Department of Defence)[45]. This summit focused on (1) resilience in conflict environments, (2) artificial intelligence for defense, and (3) biotechnology for defense. Regarding theme (3), keynote sessions were presented by Professor Dame Angela McLean of the UK Ministry of Defence, Dr. Stephanie Rogers, acting principal director of biotechnology at the US Department of Defense, and Dr. Nick Beagley, and Dr. Greg Coia of the Australian Department of Defence. Discussions and lectures covered Synthetic/Engineering Biology, dual-use applications, initiatives by the US DARPA, and Manufacturing USA's BioMADE, among other topics. At the summit, Professor Tanya Monro, the Chief Defence Scientist, presented on the efforts of the Safeguarding Australia through Biotechnology Response and Engagement alliance (SABRE) to protect and strengthen Australia's bioresearch. She discussed how SABRE plans to compile opinions on biotechnology from Australian universities, research institutions, and small and medium-sized enterprises (SMEs) and connect these with the needs of the defense and national security sectors.

(9) The Action Plan for Critical Technologies

In April 2021, the Department of Foreign Affairs and Trade announced the International Cyber and Critical Technology Engagement Strategy[46]. The strategy defines critical technologies as those that enhance national interests, including Australia's prosperity, social cohesion, and national security, and have the potential to pose risks to these interests. Critical technologies listed include cyberspace, artificial intelligence (AI), 5G, the Internet of Things (IoT), quantum computing, and synthetic biology. In relation to critical technologies, the strategy continues to prioritize the Indo-Pacific region for the diplomatic objectives of cyber and critical technologies. It aims to build new partnerships, strengthen existing ones, and enhance activities that pursue shared democratic values. The strategy outlines a fundamental policy to ensure that the supply and use of cyber and critical technologies do not endanger international peace, security, and democratic values.

On November 17, 2021, then Prime Minister Scott Morrison announced the "Blueprint for Critical Technologies," consisting of four goals and seven actions.[47] This document identifies synthetic biology as a technology that significantly enhances Australia's national interests or poses risks, listing it as one of the critical technologies of initial focus.[48]

On the same date, the Action Plan for Critical Technologies[49] was announced, detailing specific measures for

45 ADSTAR2022: https://www.dst.defence.gov.au/event/australian-defence-science-technology-and-research-summit-adstar

46 International Cyber and Critical Technology Engagement Strategy : https://www.internationalcybertech.gov.au/strategy

47 Critical Technologies Policy Coordination Office, "Blueprint": https://www.pmc.gov.au/resource-centre/domestic-policy/blueprint-critical-technologies

48 Critical Technologies Policy Coordination Office, "Critical Technologies": https://www.pmc.gov.au/resource-centre/domestic-policy/list-critical-technologies-initial-focus

49 The action plan for critical technologies: https://www.industry.gov.au/publications/action-plan-critical-technologies

63 technologies across eight categories. This plan provides a specific vision for protecting and advancing critical technologies in alignment with national interests. Synthetic biology is included in the “Biotechnology, Genetic Engineering, and Vaccines” category, comprising bio-manufacturing, biomaterials, genetic technologies, genome, and genetic sequencing, nanobiotechnology, and nanoscale robotics. Within this category, the focus is initially on genomics and genetic engineering, emphasizing genetic engineering, genome sequencing and analysis (including next-generation sequencing), and synthetic biology.

Research and development programs related to biotechnology or synthetic biology are categorized into four levels: (1) No regret, (2) Responsive support, (3) Pre-emptive support, and (4) On-shoring and regulation, with individual responses planned accordingly. Among the current biotechnology or synthetic biology programs, mRNA vaccine manufacturing technologies (sovereign mRNA vaccine capability), highlighted due to COVID-19, are specially mentioned as part of the fourth category.

(10) Other related safety regulations include:

The Food Standards Australia New Zealand (FSANZ) is responsible for setting and managing food standards based on the Food Standards Australia New Zealand Act 1991[50]. Its mission is to protect the health and safety of Australians and New Zealanders by ensuring a safe food supply.

FSANZ sets standards that apply to both Australia and New Zealand, as well as Australia-specific standards. Overall, food standards in Australia and New Zealand are known as the Food Standards Code.

The Australian Gene Technology Act 2000[51] is a national regulatory framework for genetically modified organisms. It aims to identify risks arising from or as a result of gene technology, and by regulating certain dealings with genetically modified organisms, it protects public health and safety as well as the country’s environment, managing those risks.

Australia has been a party to the Convention on Biological Diversity (CBD) since 1993, committing to fulfill its obligations under the CBD in accordance with national priorities.[52] In 1996, the Australian government approved the first National Biodiversity Strategy and Action Plan (NBSAP) showing how CBD obligations would be implemented domestically. After extensive reviews, Australia announced the third revised NBSAP, “Australia’s Strategy for Nature 2019-2030,”[53] on November 8, 2019.

2.1.3 Funding

The following is a summary of funding related to synthetic biology covering basic to applied research.

50 Australian Government’s Health, “Food Standards Australia New Zealand”

51 Office of Parliamentary Counsel, Canberra. (2000) “Gene Technology Act 2000”

52 Under the CBD, a technical expert group on synthetic biology has been established, with its Conference of the Parties (COP) deliberating on the matter. In December 2022, at COP15 held in Montreal, Canada, it was acknowledged that no conclusion had been reached on whether synthetic biology constitutes a “new issue” for discussion under the Convention on Biological Diversity (agenda item 27). It was decided that a horizon scan to analyze and interpret future prospects would be conducted, and the effectiveness of this process would be reviewed at COP16. References: https://www.nacsj.or.jp/2022/12/33376/

53 Commonwealth of Australia. (2019) “Australia’s Strategy for Nature 2019-2030”: https://www.australiasnaturehub.gov.au/national-strategy

(1) Funding for Universities and Corporations

Competitive funding for universities is primarily distributed by the Australian Research Council (ARC) and the National Health and Medical Research Council (NHMRC). Table 2-1 summarizes 39 cases and funding amounts totaling 94.46 million Australian dollars (approximately 8.46 billion yen) for universities, based on data from the Grant Information System GrantConnect[54] from January 2018 to January 2023, with synthetic biology as a keyword.

Table 2-1 Funding for Synthetic Biology Research by University from January 2018 to January 2023

University/Research Institution	Funding Amount (2018-2023, in thousand AUD)	Number of Projects		
		ARC	NHMRC	DISR
University of Queensland	3,648 (including COE 3,500)	4	0	0
Macquarie University	3,593 (including COE 3,500)	2	0	0
Australian National University	378	3	0	0
Monash University	368	5	1	0
University of Western Australia	324	3	2	0
University of Sydney	241	4	0	0
University of New South Wales	204	3	0	0
University of Melbourne	191	3	0	0
University of Newcastle	120	3	0	0
HydGene Renewables	110	0	0	1
Walter and Eliza Hall Institute of Medical Research	79	0	1	0
Flinders University	59	1	0	0
Curtin University	53	1	0	0
Queensland University of Technology	39	1	0	0
University of Technology Sydney	34	1	0	0
Total	**9,446 (about 8.46 billion yen)**	**34**	**4**	**1**

[54] GrantConnect is a comprehensive database for registering Australian government grant information. 42 cases were analyzed that hit in the search with the keyword "synthetic biology" and the date range "01-Jan-2018 to 01-Jan-2023": https://www.grants.gov.au/

The University of Queensland's "Centre of Excellence for Innovations in Peptide and Protein Science (CIPPS)"[55] and Macquarie University's "Centre of Excellence in Synthetic Biology (CoESB)" are major recipients of ARC Centres of Excellence funding (support for COE establishment, with 35 million AUD (approximately 3.29 billion yen), provided over 7 years), making up a significant portion of university grants. The ARC accounts for nearly 96% of the total funding support (90.5 million AUD; approximately 8.5 billion yen), followed by 3% from NHMRC (2.86 million AUD; approximately 240.64 million yen), and 1% from DISR (Business Research and Innovation Initiative, BRII, 1.1 million AUD; approximately 103.4 million yen). The total funding over five years[56] amounts to 94.46 million AUD (approximately 8.46 billion yen).

ARC's individual programs include various ones such as Discovery, similar to Japan's Grants-in-Aid for Scientific Research, Linkage for network formation support, and Industrial Transformation Research Hubs for industry-academia collaboration support.

NHMRC's adopted projects include applied research such as designing new therapeutic drugs using synthetic biology, receptor engineering to improve cancer immunotherapy, and developing FRET-based protein sensors for localization analysis.

HydGene Renewables, receiving funding from DISR's Business Research and Innovation Initiative (BRII), is engaged in R&D at the Macquarie University campus to produce renewable hydrogen gas from carbohydrate-containing raw materials by manipulating the genetic functions of green algae like Chlamydomonas through a synthetic biological approach. The base of HydGene Renewables' R&D originated from a student team at Macquarie University winning the Best Energy Project 2017 at the iGEM, the world competition in synthetic biology, in 2017[57]. Macquarie University, in collaboration with the CSIRO, has bioplatforms for joint research, enabling researchers to access cutting-edge infrastructure through collaborations with Bioplatforms Australia, supported by the National Collaborative Research Infrastructure Strategy (NCRIS) program, the National Biologics Facility, Phenomics Australia, and the Australian Plant Phenomics Facility.

(2) The Medical Research Future Fund (MRFF)

The MRFF, established by the Abbott government in 2015, saw its cumulative investment reach 20 billion AUD (about 1.88 trillion yen) over five years by July 2020. During the second 10-year investment plan period from 2022-23 to 2031-32, 6.3 billion AUD (about 592.2 billion yen) will be invested to support research innovation in human health, job creation, and strengthening regional industries, aiming to lead the world in medical research. Investment targets include (1) Research benefiting patients, such as clinical research and innovative treatments (1.4 billion AUD: approximately 131.6 billion yen), (2) Key research aggregating leading researchers, health professionals, and stakeholders (1.5 billion AUD; approximately 141 billion yen), (3) Support for R&D aimed at skill enhancement for of researchers and marketization (1.3 billion AUD; approximately 122.2 billion yen), and (4) Support for evidence-based translational research (2.1 billion AUD, approximately 197.4 billion yen). Recent investment amounts are summarized in Table 2-2, with 2021-22 seeing nearly double the increase compared to 2019-21.

55 CIPPS is not mentioned in the context of synthetic biology within the National Synthetic Biology Roadmap.

56 Includes the amount of ARC-COE support over 7 years.

57 Macquarie University iGEM2017: https://2017.igem.org/Team:Macquarie_Australia

Table 2-2 Annual investment amounts for R&D activities in the health and medical sector (in million AUD)[58]

Fund Name	2019-2020	2020-2021	2021-2022
NHMRC Grants	901	891	870
Medical Research Future Fund MRFF	393	580	646
Biomedical Translation Fund BTF	29	58	25
R&D Tax Incentive	246	251	267
Other	112	99	114

(3) The Cooperative Research Centres (CRC) Program[59]

The Cooperative Research Centres (CRC) program, established by the Australian government in 1990, provides funding for industry-led joint research conducted between industry, university researchers, and end-users. The program offers two types of financial support: CRC Program Grants for industry-led mid to long-term joint research focusing on the application of research for up to 10 years, and grants supporting short-term (within 3 years) joint research led by industry. Strategic oversight of this program is provided by Innovation and Science Australia[60] and its CRC Advisory Committee.

The CRC Program Grant provides funding to industry-led research centers (established concurrently with the initiation of the CRC Program Grants) aiming to utilize Australian expertise for practical outcomes beneficial to Australian businesses. This grant supports industry-led collaborative research centers for up to ten years. It is currently overseen by DISR. Grant applications target research fields across all industry sectors, requiring applicants to seek at least an equal amount of cash or investment in-kind from partners, including the applicant. The 24th round of applications started on January 13, 2023.

Since its inception, more than 5.5 billion AUD has been provided to establish 236 CRCs and 189 CRC projects, further leveraging 16.8 billion AUD in cash and investment in-kind from partners. According to DISR, CRC Grants provide a missing step between research and commercialization. They are evaluated to bring about 32.5 billion AUD in economic productivity through the commercialization of products and services using new technologies by 2025.

The main synthetic biology-related CRCs that received funding focus on areas such as future fuels, digital health, future battery industries, food loss countermeasures, future food systems, and marine bioproducts.

(4) Startup Support[61]

The Biomedical Translation Fund (BTF) is a fund under the Department of Health and Aged Care aimed at investing in early-stage biomedical companies, announced in the 2015 NISA. The total support amount is 501 million AUD (about

58 Data reprinted from "Biotechnology in Australia - 'Strategic Plan for Health and Medicine'":

59 Cooperative Research Centres Program impact evaluation: https://www.industry.gov.au/publications/cooperative-research-centres-program-impact-evaluation

60 Industry Innovation and Science Australia, https://www.industry.gov.au/science-technology-and-innovation/industry-innovation-and-science-australia

61 BTF: https://business.gov.au/grants-and-programs/biomedical-translation-fund

47 billion yen), with 250 million AUD (about 23.4 billion yen) from government funds and 251.25 million AUD (about 23.6 billion yen) from corporate funds, supporting nearly 27 startups to date, including Blade Therapeutics Pty Ltd, which develops treatments for idiopathic pulmonary fibrosis.

(5) R&D Tax Incentive[62]

Although not a support system limited to the biotechnology sector, nor a direct financial support system, the tax incentive exists as a support system for R&D where tax deductions can be obtained for research and development investments. The tax authorities and the Department of Health are collaborating to ensure it is an accessible system for companies working on clinical trials of therapeutic drugs. It has been established for over 10 years and more than 1,000 companies have received tax deductions amounting to 2.5 billion Australian dollars (approximately 235 billion yen) annually.

(6) Patent Box Initiative[63]

This initiative, announced in May 2022, is a discounted tax regime applicable to revenues generated from new patents in the medical and biotechnology sectors from July 1, 2022. A 17% discount rate is applied to the corporate income of companies in the medical and biotechnology sectors that meet certain eligibility criteria.

2.1.4 Main Research Institutions and University R&D Trends

As shown in Figure 2-2, Australian universities supported by ARC Centers of Excellence and the CSIRO work closely together and participate in the Global Biofoundry Alliance. The country also has many research institutes and private companies specializing in medical and agribio research, and actively participates in joint research with Europe and America. The following are some major Australian research institutes.

62 R&D Tax Incentive: https://www.ato.gov.au/Business/Research-and-development-tax-incentive/

63 "Patent Box - tax concession for Australian medical and biotechnology innovations", https://www.ato.gov.au/General/New-legislation/In-detail/Direct-taxes/Income-tax-for-businesses/Patent-Box---tax-concession-for-Australian-medical-and-biotechnology-innovations/#:~:text=In%20the%202021%2D22%20Budget,effective%20from%201%20July%202022 (accessed on October 2, 2022)

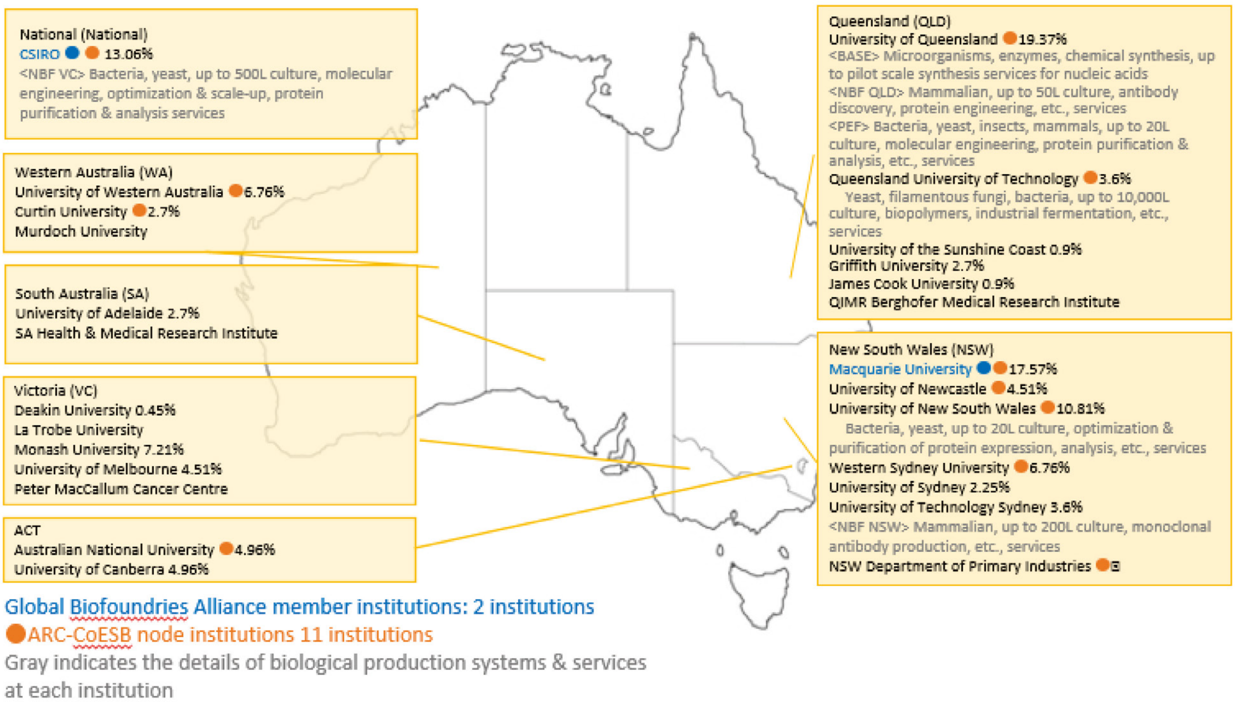


Figure 2-2 Australian Synthetic Biology Research Institutions.
(In parentheses is the proportion of synthetic biology research to the entire country based on Web of Science information from 2015-2020, created based on the “National Synthetic Biology Roadmap“)

(1) CSIRO Synthetic Biology Future Science Platform (SynBio FSP)[64]

In September 2018, the CSIRO established the Synthetic Biology Future Science Platform (SynBio FSP) to support innovation and create commercialization opportunities in the manufacturing, industrial biotechnology, environmental remediation, agriculture, biosecurity, and healthcare industries. In 2018, 13 million US dollars (approximately 1.599 billion yen) were invested in the SynBio FSP, focusing on three programs: environment and biocontrol, chemicals and fibers, and symbionts and organelles. According to Dr. Claudia Vickers, the founder and former Director of SynBio FSP (currently CSO at Eden Brew), and current Director Dr. Colin Scott, SynBio FSP has trained about 100 PhD researchers through the Future Science Fellows and SynBio FSP PhD Top-up Scholarships, across 24 laboratories (research institutions) in Australia and 17 international partner institutions[65]. It also has an International Advisory Committee consisting of about ten leading researchers, such as Professor Paul Freemont from Imperial College London, Professor John Glass from the J. Craig Venter Institute, and Professor Pamela Silver from Harvard University, working towards effective management. The CSIRO BioFoundry (a bio-production system called a “BioFoundry”) was established within SynBio FSP, offering contracted analysis of the design/build/test/learn (DBTL) process, including combinatorial gene design, DNA assembly, high-throughput strain construction, phenotypic analysis, and data analysis.

64 CSIRO SynBio: https://research.csiro.au/synthetic-biology-fsp/

65 JST/APRC workshop“Future Trends and Emerging Technologies in Synthetic Biology” 2022, https://www.jst.go.jp/aprc/en/event/2022ausjp.html

(2) Macquarie University ARC Centre of Excellence in Synthetic Biology (CoESB)

The Australian Research Council (ARC) Synthetic Biology COE (CoESB), headed by Macquarie University, aims to pioneer new approaches to microbial design to develop custom-designed microbial populations and novel synthetic enzymes. According to Professor Ian Paulsen—who has led the microbial genome sequencing project at The Institute for Genomic Research (TIGR; founded by J. Craig Venter, the representative of CoESB)—the Centre consists of 19 domestic and international research groups, 19 industrial collaborators, and 16 research partners. It has made significant contributions to the Yeast 2.0 international consortium (contributing to the synthesis of chromosomes 14 and 16)[66] and has established a presence as a hub for genome analysis in Australia, known as the Genome Foundry. In particular, the CoESB has partnered with the metabolomics facility of the Australian Wine Research Institute (AWRI), supported by a bio-platform for yeast metabolism routes, focusing on research centered on functional modifications through synthetic biology approaches. In May 2019, the Global Biofoundries Alliance (GBA) was established in Kobe, with the University of Queensland and Macquarie University (the parent body of the CoESB)[67] participating as founding members from Australia.

(3) University of Queensland (UQ) - Australian Institute for Bioengineering and Nanotechnology (AIBN)[68]

The UQ-Australian Institute for Bioengineering and Nanotechnology (AIBN) is a large-scale research institute established in 2004 and is composed of hundreds of scientists aiming to solve challenges in energy, health, and the bioeconomy. At the end of 2021, Professor Alan Rowan, the director of the research institute, announced the launch of a new facility in the field of bioeconomy research called IDEA Bio (Integrated Design Environment for Advanced Biomanufacturing)[69]. This facility, funded by NCRIS, aims to offer a comprehensive design environment for project development, including the evaluation of fermentation characteristics of strains, multi-omics characterization, and cell design. IDEA Bio collaborates with American biotechnology company Amyris Inc, American pharmaceutical company Zoetis Inc, and Dow AgroSciences Inc, to lead cutting-edge research in synthetic biology.

66 The Yeast 2.0 project is an international partnership focused on utilizing synthetic biology tools to construct the world's first synthetic eukaryotic genome. It includes major international leaders participating from institutions such as New York University (USA), Johns Hopkins University (USA), the Joint Genome Institute (USA), BGI (China), Tianjin University (China), Tsinghua University (China), Imperial College London (UK), the University of Edinburgh (UK), and Australia (hosted by Macquarie University). The results were featured in the March 10, 2017, issue of SCIENCE magazine (Vol.355, No. 6329).

67 GBA originated from discussions in 2018 about the establishment of 15 biofoundries worldwide aiming for efficient mutual operation. As of 2022, there are 30 biofoundries worldwide, with the breakdown in the Asia-Pacific region (in no particular order) being Japan (1), China (5), Australia (2), India (1), South Korea (2), and Singapore (1). The institutions are as follows: Agile BioFoundry (USA), Australian Genome Foundry (Australia), BIOFAB, University of Washington (USA), Biofactorial (Canada), The BioFoundry at UBC (Canada), BioFoundry India (India), Colorado Cyberbiofoundry (USA), CompuGene, TU Darmstadt (Germany), Concordia Genome Foundry (USA), CSIRO BioFoundry (Australia), DAMP lab, Boston University (USA), DTU Biosustain BioFoundry (Denmark), Earlham DNA Foundry (UK), Edinburgh Genome Foundry (UK), GeneMill, Liverpool (UK), iBioFAB-Illinois Biological Foundry for Advanced Biomanufacturing (USA), K-Biofoundry (KAIST KRIBB) (South Korea), Kobe Biofoundry (Japan), LARA, Laboratory Automation Robotic Assistant Biochemistry Greifswald (Germany), Living Measurement Systems Foundry, NIST (USA), London BioFoundry ICL (UK), SIAT Biofound Shenzhen (China), SJTU (Shanghai Jiao Tong University) Synbio BioFoundry (China), SKy Biofoundry Sungkyunkwan University (South Korea), SYNBIOCHEM, Manchester (UK), SynCTI, Singapore BioFoundry (Singapore), Tianjin BioFoundry-Tianjin Institute of Industrial Biotechnology (China), Tianjin University BioFoundry (China), VTT Technical Research Centre of Finland (Finland), Zhejiang University (China):https://www.nature.com/articles/s41467-019-10079-2.pdf?proof=t+target%253D

68 UQ-AIBN: https://aibn.uq.edu.au/

69 IDEA Bio has high-throughput facilities capable of designing and testing hundreds of strains in a week.
https://www.ideabio.org.au/

The facility cooperates with many university facilities such as BASE (a joint facility of the National Bioproducts Facility and Protein Expression Facility)[70], Metabolomics and Proteomics Facility (Q-MAP), and Protein Expression Facility (PEF), promoting efficient research and development.

Additionally, in synthetic biology-related research, Professor David Craik, a world-leading researcher in peptide research and protein structural analysis and the center director of ARC Centre of Excellence for Innovations in Peptide and Protein Science (CIPPS), is discovering new proteins and peptides from Australia's diverse flora and fauna, synthesizing novel proteins and peptides through functional analysis. One of the three flagship research pillars highlighted is biosynthetic technology for peptide and protein engineering, utilizing technologies such as the RaPID system developed by Professor Hiroaki Suga of the University of Tokyo, identifying novel peptides such as the SARS-CoV-2 spike protein.

2.1.5 Trends in Major Industries

In 2020, Australia accounted for 15.3% of the synthetic biology market in the Asia-Pacific region, with projections indicating growth from 275 million US dollars (approximately 33.8 billion yen) in 2021 to 863 million US dollars (approximately 106.1 billion yen) by 2026, at a compound annual growth rate (CAGR) of 25.7% during the period.[71] The Australian biotechnology-related industry as a whole mainly comprises medical technology, digital health, pharmaceuticals, and food & agricultural companies. It is seeing particularly notable growth in pharmaceuticals and food & agriculture, which are also related to synthetic biology.

According to a 2019 report[72] by the Australian corporate body AusBiotech, biotechnology-related industries have shown a 16% increase since 2017. The number of companies has grown by about 15%, with a market value estimated at 1.7 billion US dollars (approximately 209.1 billion yen).[73] These industries are relatively widely distributed but are particularly concentrated in Victoria (707 companies in 2019) and New South Wales (652 companies in the same year), with 73% of all companies located in these states. Investments in research by companies have reached 2 billion US dollars (approximately 246 billion yen) by 2020-21, mainly in genomics, translational research, brain tumors, and clinical research. The Department of Health and Aged Care (DHAC)'s Genomics Health Futures Mission aims to invest 500 million US dollars (approximately 61.5 billion yen) over 10 years from 2018-19 in genomics research to improve tests and diagnostics that contribute to personalized treatment. In March 2022, AusBiotech announced the "Biotechnology Blueprint: A Decadal Strategy for the Australian Biotechnology Industry 2022-2032."[74] The blueprint was based on consultations with academia, industry, and government, and aims to make the Australian biotechnology industry a cornerstone of the future economy. It focuses on promoting translational research and innovation creation, supporting dual focus (universities, companies) on commercialization, implementing special projects such as scaling up small businesses, enhancing the competitiveness of Australian researchers in the international arena, and building

70 UQ-BASE: https://basefacility.org.au/

71 Markets and Markets, "Synthetic biology market - Global forecast to 2026," 2021.

72 AusBiotech is an industry body comprising over 3,000 members in the Australian life sciences sector, including therapeutics, medical technology (devices, diagnostics), digital health, and agricultural biotechnology, and has been active for over 35 years. Australia's Life Sciences Sector Snapshot 2019: https://www.ausbiotech.org/documents/item/589

73 Mainly from Synthetic Biology Market-Global Forecast to 2026.

74 Biotechnology Blueprint2022: https://www.ausbiotech.org/documents/item/703

sovereign capabilities in biotechnology, among eight[75] recommendations. These recommendations are aligned with the "Biotechnology in Australia – Strategic Plan for Health and Medicine" by the Department of Health mentioned earlier in 2.1.2 (8).

Additionally, MTPConnect[76], a non-profit organization established in 2015, aims to foster growth and academic-industry collaboration in the medical technology, biotechnology, and pharmaceutical sectors. After announcing its first Sector Competitiveness Plan (SCP) in 2016, MTPConnect revised the plan again in 2022. The SCP plays a leading role in clarifying the commercial research potential and outcomes of this industry. In particular, the plan's Growth Centre operates five MRFF programs: BioMedTech Horizons (MBTH), Biomedical Translation Bridge (BTB), Researcher Exchange and Development within Industry (REDI), Targeted Translation Research Accelerator (TTRA), and Clinical Translation and Commercialisation Medtech (CTCM), enabling commercialization and support for the scaling of startups and small businesses[77].

Notable companies here include four startups among the ten deep tech startups identified in the National Synthetic Biology Roadmap, closely associated with ARC-CoESB and the CSIRO:

(1) Bondi Bio (NSW) company[78]

Established in 2018, Bondi Bio develops Cyanoworks (tm), using cyanobacteria with high metabolic efficiency as chassis strains for producing fragrances, cosmetics, nutritional supplements, pharmaceuticals, aromatic chemicals, and matter production. It produces astaxanthin, squalene (shark liver oil), sandalwood oil, and nootkatone (a grapefruit fragrance component) in a carbon-neutral manner. In October 2021, it won the UN FAO's Startup Innovation Award (UN WFF Innovator of the Year). It has partnerships with the University of Technology Sydney, the University of New South Wales, Macquarie University, the University of Queensland, the Marine Bioproducts CRC, and ARC-CoESB.

(2) MicroBioGen (NSW) company

Founded in 2001 by Dr. Philip Bell, Dr. Paul Attfield, and four others from Macquarie University, MicroBioGen's strength lies in owning a library of non-genetically modified yeast strains (exempt from GM regulations). In collaboration with Denmark's Novozymes, it has developed strains like Innova®Drive, successfully mass-producing first-generation bioethanol. It has also succeeded in developing an optimization process for second-generation bioethanol production with an 8 million Australian dollar grant (ARENA) from the Australian government. MicroBioGen develops and optimizes industrial yeast strains suitable for producing high-protein feed. The company developed first-generation biofuel yeasts under the "Innova" brand, with Novozymes, a major partner and investor, handling sales and marketing.

75 AusBiotech: "Industry-backed plan to navigate Australian biotech into the future", 12 May 2022, https://www.ausbiotech.org/news/industry-backed-plan-to-navigate-australian-biotech-into-the-future (accessed on October 2, 2022)

76 MTPConnect :https://www.mtpconnect.org.au/

77 "Sector Competitiveness Plan", MTPConnect: https://www.mtpconnect.org.au/images/2022_MTPConnect_SectorCompetitivenessPlan.pdf (accessed on October 2, 2022)

78 Bondi Bio company: https://www.bondi.bio/about

(3) PROVECTUS ALGAE (QLD) company

Founded in 2018, Provectus Algae is a startup with biotechnology manufacturing technology[79] based on microalgae. Founder and marine biotechnologist Dr. Nusqe Spanton, in cooperation with the University of the Sunshine Coast's Genetics Research Centre (now the Centre for Bioinnovation), developed a novel chloroplast expression system for commercial applications, including large-scale and rapid manufacturing of genetically modified algae.

In October 2020, it successfully raised 3.25 million dollars (approximately 399 million yen) from Hong Kong's Vectr Ventures in a seed round to accelerate the commercialization of their in-house developed synthetic biology platform for algae, which includes proprietary lighting equipment. In 2022, its further improved and optimized its expression system using the CSIRO's Innovation Connections[80] program that provides support for SMEs, developing protocols for the commercial production of peptides and proteins. The company plans to launch four commercial products in 2023 and is aiming to expand its staff and expand into the United States.[81]

(4) Eden Brew (NSW) company

Eden Brew, a food tech startup aiming to produce animal-free milk, was founded in 2021 with funding from Norco, Australia's largest dairy cooperative, and the CSIRO's venture capital Main Sequence. Using recombined yeast protein production technology developed by the CSIRO, it produces six common milk proteins, including casein and β-lactoglobulin. In 2022, it hired Dr. Claudia Vickers, former director of the CSIRO's Future Science Platform, as Chief Science Officer (CSO). Dr. Vickers is a founder of Synthetic Biology Australasia, a member of the expert working group on Australia's national synthetic biology and infrastructure investment plan, and co-chair of the World Economic Forum's Global Future Council on the Future of Synthetic Biology, as well as serving on advisory committees including Food Standards Australia New Zealand (FSANZ).

2.2 China

China's total research and development investment for the year 2022, as announced by the National Bureau of Statistics (preliminary figures), increased by 10.4% from 2021 to 3.087 trillion yuan (about 59 trillion yen), with the percentage of GDP increasing by 0.12 points from 2021 to 2.55%. This marks an annual average growth rate of 8% since the start of the 13th Five-Year Plan in 2016, exceeding the growth rate of over 7% targeted in the 14th Five-Year Plan (2021-2025). In particular, basic research funding increased by 7.4% from the previous year to 195.1 billion yuan (about 3.7 trillion yen), making up 6.32% of the total R&D investment and maintaining a level above 6% for four

79 Their system, called Precision Photosynthesis®, adjusts gene expression through control by light, enhancing cell proliferation and biomanufacturing productivity to produce novel compounds for food, cosmetics, and agricultural products. https://provectusalgae.com/microalgae-biotechnology-biomanufacturing-platform/

80 Innovation Connections: https://www.csiro.au/en/work-with-us/funding-programs/SME/Innovation-Connections/About-the-program

81 CSIRO:https://www.csiro.au/en/work-with-us/funding-programs/SME/Innovation-Connections/Medical-Pharmaceuticals-Success-Stories/Provectus-Algae?utm_source=Snapshot_October_2022&utm_medium=newsletter&utm_campaign=Snapshot_October_2022

consecutive years[82].

While the exact amount of investment in the field of synthetic biology is not specified, the 2021 annual report to Congress submitted by the U.S.-China Economic and Security Review Commission in November 2021 states that as part of its strategy in synthetic biology, the central and local governments combined have invested over 100 billion dollars (12.3 trillion yen) in the biotechnology sector[83].

China has been investing in R&D through collaboration between industry, academia, and government and promoting biotechnology research, including synthetic biology, with the expectation that it will solve problems in the fields of medicine, agriculture, environmental restoration, and natural resource utilization and bring about economic and social development in the country. The government is also working to attract human resources from other countries and develop high-level human resources. In recent years, the “Fourteenth Five-Year Plan for National Economic and Social Development and the Outline of Distant Objectives for 2035,” announced in 2021, mentions synthetic biology technology with keywords such as “disruptive,” “strategic needs,” “frontier technology,” and “key technology,” and emphasizes the need for medium- to long-term development to become a world leader.

The starting point for China’s initiatives in synthetic biology was the 2008 Xiangshan Science Conference (“香山科学会议第322学术讨论会综述 2008”)[84], held in Beijing, where “synthetic biology” was adopted as a theme for the first time, with attendees including academician Zhang Chunting of the Chinese Academy of Sciences, calling for enhanced government support for the field, recognizing its significant value to the future bioeconomy. Following this conference, the “Key Laboratory of Synthetic Biology” was established by the Chinese Academy of Sciences in 2008, marking the first official government initiative in synthetic biology in China. Since then, the field has rapidly developed in China through active research support from the Ministry of Science and Technology to the Chinese Academy of Sciences, Chinese Academy of Engineering, and various universities under the national key research and development programs (then known as the “863 Program”, “973 Program”), and platform building through expanding sequencing and oligonucleotide synthesis capabilities led by major companies such as the Beijing Genomics Institute (BGI)[85]. The Chinese government is also proactive in establishing biobanks closely related to genome analysis information. The China National GeneBank (CNGB), established in Shenzhen by the National Development and Reform Commission in 2011 (opened in 2016), is China’s first national-level gene storage bank. It features three banks: Biorepository, Bioinformatics Data Centre, Living Biobank, and two platforms: Digitalization Platform, Synthesis and Editing Platform. The China National GeneBank DataBase (CNGBdb) works to database this information[86]. Currently,

82 “China’s research and development investment in 2022 exceeds 3 trillion yuan”, CRIonline, January 23, 2023 https://japanese.cri.cn/2023/01/23/ARTIngCJezQjHA3nzckUTHd7230123.shtml#:~:text=%E5%9B%BD%E5%AE%B6%E7%B5%B1%E8%A8%88%E5%B1%80%E3%81%8C%E3%81%93%E3%81%AE%E3%81%BB%E3%81%A9,%EF%BC%85%E3%81%AB%E9%81%94%E3%81%97%E3%81%A6%E3%81%84%E3%81%BE%E3%81%99%E3%80%82

83 2021 REPORT TO CONGRESS of the U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION, NOVEMBER 2021, https://www.uscc.gov/sites/default/files/2021-11/2021_Annual_Report_to_Congress.pdf

84 The Xiangshan Science Conference, initiated in 1993 by the Ministry of Science and Technology and supported by both the Ministry and the Chinese Academy of Sciences, aims to provide a free discussion forum for academics. Supporting organizations include the National Natural Science Foundation of China, Chinese Academy of Sciences, Chinese Academy of Engineering, Ministry of Education, Central Military Commission Science and Technology Commission, China Association for Science and Technology, National Health and Family Planning Commission, and the Ministry of Agriculture:

85 LeiPei et al. (2011) “Synthetic biology: An emerging research field in China”, *Biotechnology Advances* Vol 29, Issue 6, pp804-814

86 China National GeneBank DataBase (https://doi.org/10.25504/FAIRsharing.9btRvC (accessed on June 10, 2022))

China is said to have the largest capacity for genome storage in the world.[87]

One iconic institution is the Institute of Synthetic Biology established by the Chinese Academy of Sciences in Shenzhen in 2017. This institute began cooperating with the Shenzhen Institute of Advanced Technology (SIAT) in 2018, opening several research centers such as for Quantitative Synthetic Biology, Synthetic Genomics, Synthetic Biochemistry, Synthetic Microbiome, Genome Engineering and Therapy, and Synthetic Immunology, becoming a central figure in China’s synthetic biology field.

2.2.1 Government Organizations and Systems

The organization and research development system of the Chinese government is shown in Figure 2-3. The core role in formulating China’s science and technology policy is played by the Communist Party of China and the State Council, with the Ministry of Science and Technology (MOST) under its guidance.

The national budget and final accounts related to science and technology are jointly prepared by MOST and the Ministry of Finance and approved by the State Council[88]. China’s funding system is based on centralized management by the central government. Specifically, under the leadership of the State Council and MOST, medium to long-term scientific development plans are established in accordance with the country’s basic policy and the needs of science and technology development, and these are made public as central policies. In response, local (provincial, municipal, autonomous region) governments and various bureaus adjust their policies to the specific conditions of their regions and bureaus and implement various measures[89]. Under MOST, there is the National Natural Science Foundation of China (NSFC), a funding organization supporting basic research. Following the plan to deepen the reform of party and state institutions in 2018, NSFC was transferred from the State Council to the jurisdiction of MOST, becoming an organization with greater independence than before. Amongst synthetic biology-related research and development in China, MOST oversees major research and development projects. Moreover, while research institutions such as universities, the Chinese Academy of Sciences, and the Chinese Academy of Agricultural Sciences are central to national research and development project promotion, many also receive support from local city governments and cooperate with companies. The Chinese Academy of Sciences is placed directly under the State Council and is a large organization with research institutes, universities, think tanks, publishing houses, and spin-off companies under its umbrella.

87 U.S. CSET Roll Call. (2021) “China’s amassing of genomic data highlights global biotech race: https://cset.georgetown.edu/article/chinas-amassing-of-genomic-data-highlights-global-biotech-race/

88 JST Asia-Pacific Research Center “Promotion of Basic Research in China and the Future of ’Scientific Research Management’ Reform” (APRC-FY2021-RR01) pp. 33-34, partially reproduced.

89 China’s funding system is divided into three levels, starting with central-level funding including the Ministry of Science and Technology, Ministry of Education, National Development and Reform Commission, followed by local-level funding by local provinces and cities’ science and technology agencies, finance bureaus, and finally, funding conducted independently by some private organizations and companies. (Ibid., APRC-FY2021-RR01, p151)

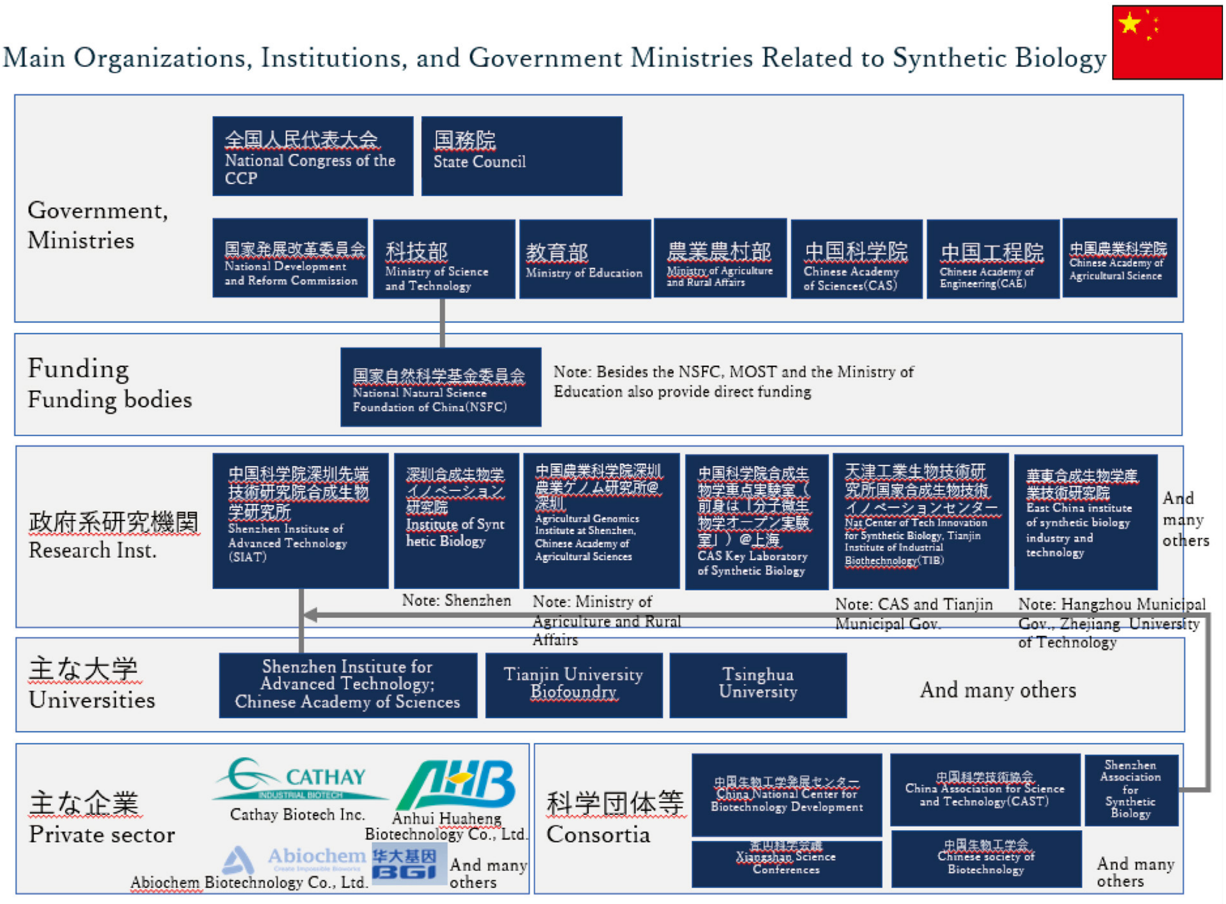


Figure 2-3 Main organizations and institutions related to synthetic biology in China

2.2.2 Major Policies and Key Issues (Central Government)

China formulates its economic and social policies in five-year intervals. The State Council announced the “Outline of the National Medium and Long-Term Science and Technology Development Plan (2006-2020)” in 2006, and Table 2-3 shows the main biotechnology-related items related to synthetic biology in policies since then[90]. According to the 2021 annual report to Congress[91] by the U.S.-China Economic and Security Review Commission, the Chinese government (central and local governments) has invested over 100 billion dollars (about 127 trillion yen) in research and development in the field of biotechnology, including synthetic biology. The strengthening of companies through M&A has also become active, and in 2017, the acquisition of the Swiss pesticide company Syngenta by ChemChina for 43 billion dollars (about 5.461 trillion yen) became the largest acquisition of a foreign company by China at the time. China’s the increasingly active collection of human and non-human genome information in biobanks through cooperation and support with other countries is also noteworthy.

90 JST China Comprehensive Research & Sakura Science Center (currently Asia and Pacific Research Center), “The Policy Changes and Development History of Science and Technology in China,” March 2019.

91 U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION, â€œ2021 REPORT TO CONGRESS of the U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION, ONE HUNDRED SEVENTEENTH CONGRESS FIRST SESSION, U.S. Government Publishing Office, https://www.uscc.gov/sites/default/files/2021-11/2021_Annual_Report_to_Congress.pdf (accessed November 2021)

Table 2-3 Changes in Policies in the National Science and Technology Five-Year Plans since 2006 (Excerpts related to Synthetic Biology)

Plan	Period	Item	Key Areas/Fields (Excerpts)
11th National Science and Technology Five-Year Plan	2006-2010	Promotion of Independent Innovation	Information, life, space, ocean, nano, new materials, etc.
		Focus on development of high-tech industries	(2) Bioindustry (out of 8)
12th National Science and Technology Five-Year Plan	2011-2015	Major national science and technology projects[92]	(8) Genetic engineering for biological breeding (9) Development of major new drugs (out of 11)
		Strategic emerging industries	(3) Bioindustry (out of 7)
		Advanced technology fields	(2) Bio and pharmaceutical technology (out of 10)
13th National Science and Technology Innovation Five-Year Plan	2016-2020	Implementation of major science and technology projects	(7) Independent innovation in breeding technology and seed industries (out of 15)
		Improvement of international competitiveness in industrial technology	(1) Advanced agricultural technology (7) Advanced biotechnology (out of 10)
		Strengthening basic research	**Strategic basic research aimed at societal needs** (1) Genetic improvement of agricultural products (out of 9) **Advanced basic research** (3) Protein complexes and control of life processes (8) Synthetic biology (9) Genome editing (out of 13)

92 Support from the 863 Program and the 973 Programs (integrated into the "National Key Research and Development Programs" in 2016), international cooperation program on the synthesis of eukaryotic yeast genomes "Synthetic Yeast Genome Project (Sc2.0)" with Chinese teams from Peking University, Tsinghua University, Shenzhen BGI, and the United States, etc., completed the design and total synthesis of four chromosomes: *syn II*, *syn V*, *syn X*, *syn XII*.

Fourteenth Five-Year Plan for National Economic and Social Development and the Outline of Distant Objectives for 2035 (Science, Technology & Innovation)	2021-2026 (up to 2035 as a distant vision)	Part Two: Adhere to innovation-driven development and comprehensively build new advantages in development Chapter Four: Strengthen national strategic science and technology Section Two: Enhance breakthroughs in science and technology driven by original innovation	Implement strategic science plans and science projects in fundamental core areas related to national security and development. Execute major national science and technology projects targeting frontier areas such as artificial intelligence, quantum information, integrated circuits, life and health, brain science, biological breeding, aerospace science and technology, the deep earth and deep sea. **[Key Initiatives in Science and Technology Frontier Areas]** **05 Genetics and Biotechnology** Research into and application of genomics, technological innovations in genetic cells, genetic breeding, synthetic biology, and biopharmaceuticals; innovation in vaccines, research and development into in vitro diagnostics and antibody drugs, produce significant new varieties of crops, livestock, poultry, aquatic products, and agricultural microorganisms, research, and development of critical technologies for biosafety
		Section Four: Construction of Major Science and Technology Innovation Platforms	Support Beijing, Shanghai, and the Guangdong-Hong Kong-Macao Greater Bay Area in forming international science and technology innovation centers, constructing comprehensive national science centers in Beijing Huairou, Shanghai Zhangjiang, the Greater Bay Area, Anhui Hefei, and support eligible regions to build regional science and technology innovation centers. **[Column 3: National Major Scientific and Technological Infrastructure]** **04 Improvement of People's Livelihood** Translational medicine research facilities, multi-mode trans-scale biomedical imaging facilities, phenotype and genotype research facilities for model animals, experiment sites for earthquake science, numerical simulators for earth systems, etc., will be constructed.

In addition to the above, the State Council's "Outline of the National Medium and Long-Term Science and Technology Development Plan (2006-2020)," announced in 2006, is positioned as the cornerstone of China's science and technology policy for the next 15 years. It highlights key areas such as genetic engineering, new drug development, infectious diseases, biotechnology, protein research, and developmental and reproductive research. Furthermore, the "Made in China 2025" initiative (2015) emphasizes biopharmaceuticals and high-performance medical equipment, and the "Outline of the National Innovation-Driven Development Strategy 2016-2030)" prioritizes health technology as a priority effort.

The "Outline of the National Medium and Long-Term Science and Technology Development Plan (2021-2035)" includes the construction of national laboratories in fields such as quantum information and AI, biomedicine, as well as the restructuring of existing key national laboratories. It also focuses on strengthening basic research and positioning AI, quantum information, integrated circuits, life and health, brain science, genetics & bio-breeding, space science technology, the deep earth / the deep sea as key frontier fields. This development plan outline was scheduled for publication before March 2021, but was postponed due to prioritization of responses to the COVID-19 pandemic.

Additionally, prior to the announcement of the "Fourteenth Five-Year Plan for National Economic and Social Development and the Outline of Distant Objectives for 2035," on September 25, 2020, the National Development and Reform Commission issued the "Guiding Opinions on Expanding Investment in Strategic Emerging Industries and Cultivating Strengthened New Growth Points and Growth Poles."[93] This guidance focuses on industries designated and invested in as strategic emerging fields since 2016, aiming to expand investment to accelerate the transformation of the industrial structure and achieve advanced and high-quality economic development. The information on synthetic biology was taken from the source below.

Accelerating the Pace of Innovation and Development in the Bio-Industry

Key industrial projects such as innovative vaccines, *in vitro* diagnostics and detection reagents, and antibody pharmaceuticals are being accelerated, and the upgrading of vaccine types and processes is being promoted. The construction of the national bio-safety risk prevention and management system is to be systematically planned, with increased investment in bio-safety and emergency response. The construction of a national biological product inspection and verification innovation platform is to be strengthened, and the construction of research and development centers for genes, cells, and genetic breeding technologies, synthetic biology innovation centers, and biopharmaceutical technology innovation centers will promote the healthy development of biotechnology. The examination and approval mechanism for traditional Chinese medicine will be reformed and improved, and the research and development and industrial development of traditional Chinese medicine will be promoted. Projects will be implemented that benefit biotechnology to create markets for self-innovative pharmaceuticals, medical devices, and other products. (Responsible departments: National Development and Reform Commission, Health Commission, Ministry of Science and Technology, Ministry of Industry and Information Technology, National Administration of Traditional Chinese Medicine, State Administration for Market Regulation, etc.)

On May 10, 2022, the National Development and Reform Commission issued the "14th Five-Year Plan for the Development of the Bio-economy"[94] in relation to policies in the five-year plan. The development plan focuses on whole genome sequencing, systems biology, synthetic biology, and artificial intelligence (AI)-aided breeding technologies and promotes the creation of artificial proteins and food development using synthetic biology. This is prioritized content in the aforementioned Fourteenth Five-Year Plan for National Economic and Social Development

93 国家発展改革委員会, "关于扩大战略性新兴产业投资培育壮大新增长点增长极的指导意见　发改高技1409号," 2020. [Online]. Available: https://www.ndrc.gov.cn/xxgk/zcfb/tz/202009/t20200925_1239582.html?code=&state=123. [Accessed January 2022].

94 National Development and Reform Commission website: https Commentary by 徐涛・, Member of the Chinese Academy of Sciences:https://www.ndrc.gov.cn/xxgk/jd/jd/202205/t20220509_1324432.html Commentary by 馬炎和・天津市人民代表大会常務委員会副主任兼中国科学院天津工業研究所所長, on the perspective of biological manufacturing: https://www.ndrc.gov.cn/xxgk/jd/jd/202205/t20220510_1324454.html

and the Outline of Distant Objectives for 2035. Of note, however, the shift from the traditional "scale-oriented" approach to a "quality-oriented" approach is a new perspective. Also, the statement regarding "establishing and improving world-class scientific and technological facilities and innovative platforms and providing active support to support the development of biotechnology," citing the United States, Germany, the United Kingdom, France, and Japan, aims to generate innovation through the support of high-level national research institutions and universities, support for innovative projects, leadership development, and the construction of high-level bio-industry clusters. (Note: Or "highlights the importance.") It particularly emphasizes Beijing, Shanghai, and the Guangdong-Hong Kong-Macao Greater Bay Area as international science and technology innovation centers led by China. Although not directly related to the policy, policies related to peak carbon and carbon neutrality (dual carbon) announced by the State Council also include research and development using synthetic biology methods from the perspective of improving the production efficiency of bioenergy and require ongoing attention.

Although not directly linked to policy, of central level interest is President Xi Jinping's speeches at the academic conferences of the Chinese Academy of Sciences and the Chinese Academy of Engineering, where in 2018, he used the word "synthetic biology" for the first time, and in 2021, touched on the importance of life ethics from the perspective of "synthesis and design of life." The relevant excerpts are as follows, both in line with the national policy at the time.

(1) May 28, 2018, 19th Academic Conference of the Chinese Academy of Sciences and the 14th Academic Conference of the Chinese Academy of Engineering

> "Since the beginning of the 21st century, the world's technological innovation has entered an unprecedentedly concentrated and active period, a new round of technological revolution and industrial transformation is reshaping the world's innovation map and restructuring the world's economic structure. New generation information technologies, as represented by artificial intelligence, quantum information, mobile communications, the Internet of Things, and blockchain, are accelerating revolutionary applications, and life sciences, as represented by synthetic biology, gene editing, brain science, and regenerative medicine, are creating new transformations."[95]

(2) May 28, 2021, 20th Academic Conference of the Chinese Academy of Sciences, the 15th Academic Conference of the Chinese Academy of Engineering, and the 10th National Conference of the China Association for Science and Technology

> "Humanity has entered an era of intelligent interconnection of everything, integrating humans, machines, and objects. Basic and applied research in life sciences is rapidly developing. Through scientific and technological innovation, research on biological macromolecules and genes has not only benefited humanity by enabling understanding of and the evolution of life but has also reached a stage of regulation as an ethical issue in life synthesis and design."[96]

95 Chinese Academy of Sciences, "在中国科学院第十九次院士大会、中国工程院第十四次院士大会上的讲话," May 2018: https://www.cas.cn/zt/hyzt/ysdh19th/.

96 Xi Jinping: Speech at the 20th Conference of the Chinese Academy of Sciences. (2021) "中国工程院第十五次院士大会、中国科协第十次全国代表大会上的讲话," May 28, 2021: https://www.cas.cn/zt/hyzt/ysdh20th/yw/202105/t20210528_4790360.shtml

2.2.3 Major Policies and Key Issues (Local Governments)

Following the "Fourteenth Five-Year Plan for National Economic and Social Development and the Outline of Distant Objectives for 2035," various provinces and cities have published plans related to the advancement of their industries[97]. In China, local governments, such as provinces and cities, are also supporting research and development through platform construction and startup support based on each policy. Among them, particularly in Shanghai Zhangjiang and Shenzhen, research and development plans related to synthetic biology are planned at the four major national science centers (comprehensive national science centers: Beijing Huairou, Anhui Hefei, Shanghai Zhangjiang, and Shenzhen) approved by the National Development and Reform Commission and the Ministry of Science and Technology, and focused initiatives are also indicated in Zhejiang Province and Shanxi Province. Figure 2-4 provides an overview of this. In addition, policies related to synthetic biology in various provinces and cities are compiled in appendix table A-3.

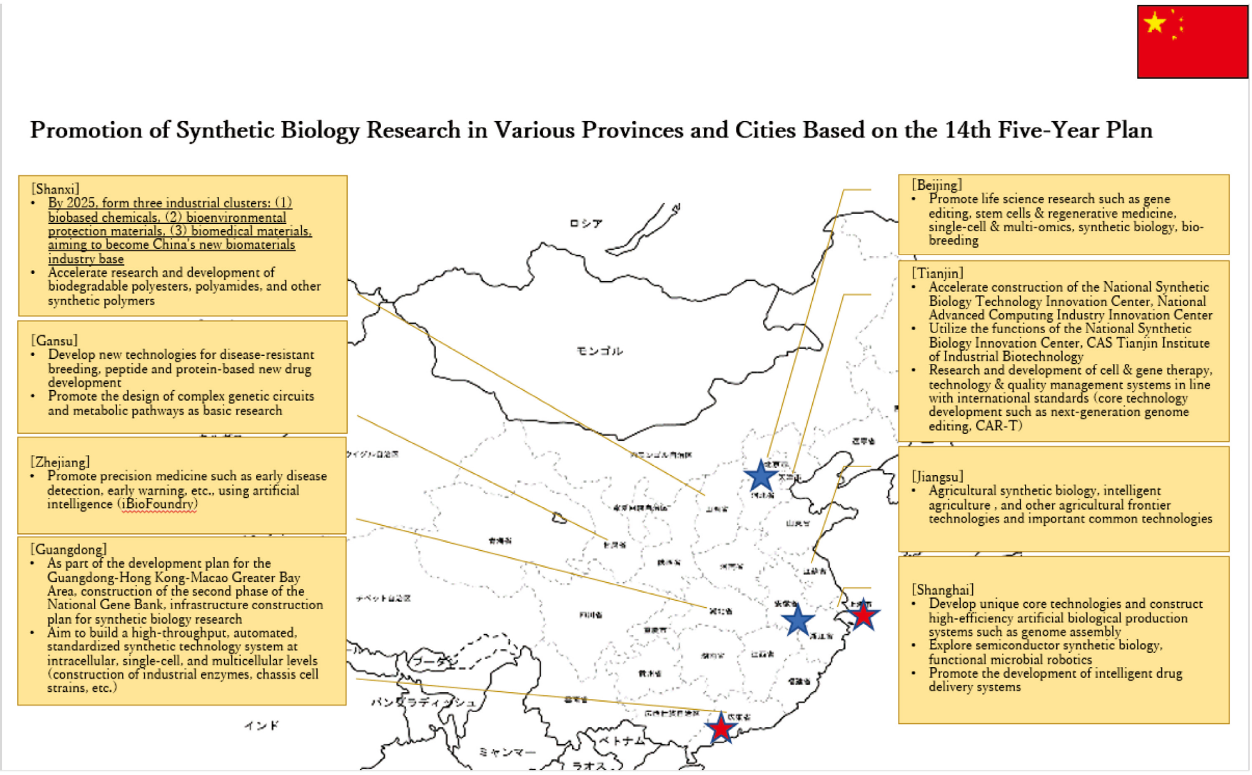


Figure 2-4 "Promotion of Synthetic Biology Research in Various Provinces and Cities Based on the 14th Five-Year Plan"

Local science and technology development funds supporting these local government policies are intended to support the four areas listed in Article 5 (free exploration-type basic research, construction of science and technology

[97] Ministry of Science and Technology of China, "Ministry of Science and Technology & Local Science and Technology": http://www.most.gov.cn/dfkj/bj/

innovation bases, deployment of science and technology achievements and technology transfer, and construction of innovation ecosystems) of the management measures for science and technology development funds in local regions guided by the central government issued in November 2021[98].

Table 2-4 lists the top 10 provinces and cities for the 2022 budget of science and technology development funds for local governments guided by the central government (total of 4.5 billion yuan (about 85.5 billion yen))[99]. According to the “Statistical Bulletin of National Investment in Science and Technology in 2020” by the National Bureau of Statistics, the national fiscal expenditure on science and technology in 2020 was a total of 1.95 trillion yuan (about 19.1805 trillion yen (central government 375.82 billion yuan (about 7.1495 trillion yen), local governments 633.68 billion yuan (about 12.399 trillion yen))[100]. Based on the same statistics, expenditure in research and development from local governments in 2020, including to the private sector (experiments/development), is listed in Table 2-5. In the breakdown, enterprises account for 76.6% of this expenditure. Regionally, there are 8 provinces and cities, including Guangdong Province and Jiangsu Province, where investment in R&D exceeded 100 billion yuan (approximately 1.9 trillion yen). The budgets in the table are not limited to synthetic biology research, but among the budgets from the central government to local governments, as well as those by local governments, the budget allocation for Guangdong Province stands out amongst the national science centers, indicating a situation that could well be described as a new dawn of scientific research.

Table 2-4 Budget for Local Science and Technology Development Funds Guided by the Central Government in 2022 (Top 10)

No.	Province/City	Budget (Ten Thousand Yuan)
1	Guangdong	34,500
2	Sichuan	31,900
3	Jiangsu	27,500
4	Zhejiang	26,000
5	Shandong	25,300
6	Anhui	20,000
7	Hubei	18,500
8	Henan	18,000
9	Shaanxi	15,700
10	Hunan	14,800
Total for All Provinces/Cities		450,000

98 Central People’s Government. (2021)“关于印发《中央引导地方科技发展资金管理办法》的通知财教,” No. 204, November 2021: http://www.gov.cn/zhengce/zhengceku/2021-12/22/content_5663957.htm.

99 Ministry of Finance of the People’s Republic of China. (2022) “关于下达2022年中央引导地方科技发展资金预算的通知,” No. 88: http://jkw.mof.gov.cn/gongzuotongzhi/202204/t20220429_3807720.htm

100 National Bureau of Statistics of China. (2021) “2020年全国科技经费投入统计公报,” September 22. Final figures for fiscal expenditures of central and local governments : http://www.stats.gov.cn/tjsj/tjgb/rdpcgb/qgkjjftrtjgb/202109/t20210922_1822388.html

Table 2-5 Research and Development Expenditure by Local Governments in 2020

No.	Province/City	Research and Development Expenditure (Billion Yuan)	Rate of Investment in Research and Development (%)
1	Guangdong	3479.9	3.14
2	Jiangsu	3005.9	2.93
3	Beijing	2326.6	6.44
4	Zhejiang	1859.9	2.88
5	Shandong	1681.9	2.30
6	Shanghai	1615.7	4.17
7	Sichuan	1055.3	2.17
8	Hubei	1005.3	2.31
9	Henan	901.3	1.64
10	Hunan	898.7	2.15
Total for All Provinces/Cities		24393.1	2.40

2.2.4 Funding

The National Natural Science Foundation of China (NSFC), which was transferred from a direct organization under the State Council to the management of the Ministry of Science and Technology (MOST) in 2018, funds basic research fields in China. Figure 2-5 summarizes the number of projects related to the field of synthetic biology from 2010 to 2019[101, 102].

Between 2010 to 2019, there was a clearly increasing trend in the number of project applications and funding in the field of synthetic biology. Out of a total of 3,258 applications, 793 were accepted (acceptance rate of 24%), distributing a total of 567 million yuan (about 10.7 billion yen). It should be noted that NSFC funding primarily supports basic research, and so this does not represent overall funding trends for synthetic biology in China.

101 杜全生, 洪伟, 祖岩. (2020) “2010—2019年国家自然科学基金资助合成生物学领域情况”, *合成生物学*, 1(3): 385-394 doi: 10.12211/2096-8280.2020-06

102 Information on individual projects is also available from the LetPub website: https://www.letpub.com.cn/index.php?page=grant#fundlisttable

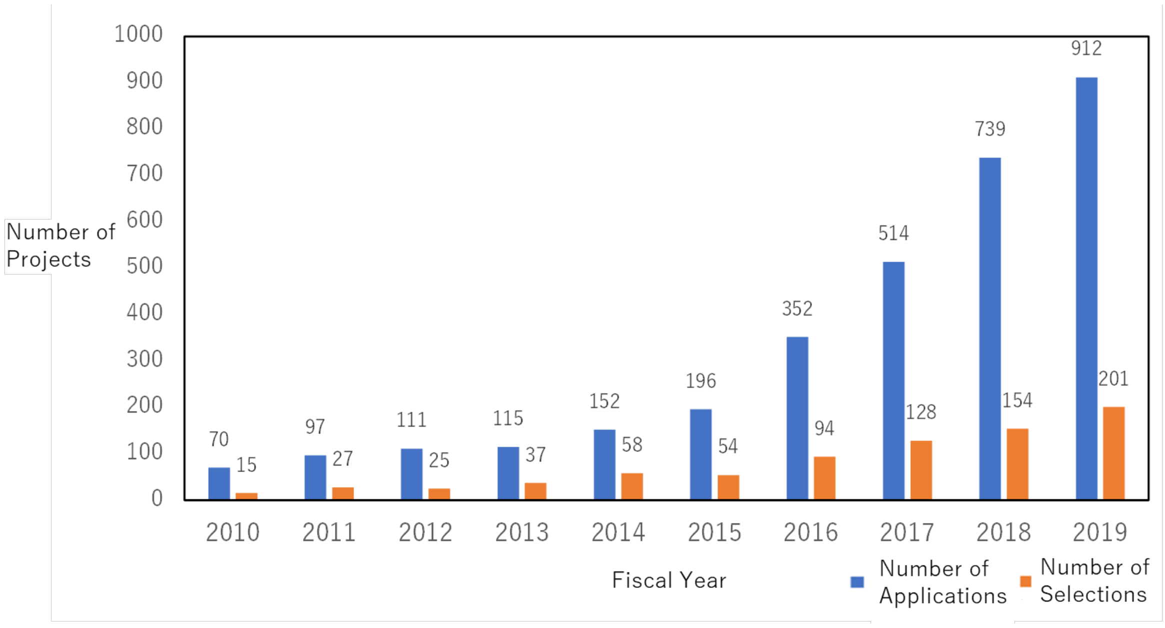


Figure 2-5 Number of Projects in the NSFC Related to the Field of Synthetic Biology (2010-2019)

In the general program (面上类项目), the NSFC’s main funding program, 97 projects including keywords such as genome editing and chassis cell & model animal construction (total of 45.44 million yuan (about 863.36 million yen, approximately 9 million yen per project)) were accepted. Recent efforts in artificial genome synthesis include 4 projects (total of 1.29 million yuan (about 24.51 million yen, approximately 6 million yen per project)), gene circuit construction includes 17 projects (8.11 million yuan (about 154.1 million yen, approximately 9 million yen per project)), and studies related to synthetic metabolic networks include 104 projects (49.06 million yuan (about 932.14 million yen, approximately 9 million yen per project)). A significant portion of the research subjects are microorganisms such as E. coli and yeast (62%, 158 institutions), with others including plants such as rice, wheat, and sugar beet (62 institutions), animals such as mice and primates (45 institutions), and humans (74 institutions).

Within the talent development program (人才类项目), projects related to synthetic biology include 7 innovative group research programs (创新群体研究项目) funded with 43 million yuan (approximately 817 million yen, about 116.71 million yen per project), 6 National Outstanding Young Scientists Fund programs (国家杰出青年科学基金项目) with funding of 22.5 million yuan (approximately 427.5 million yen, about 71.25 million yen per project), and 15 Excellent Young Scientists Fund programs (优秀青年科学基金项目) funded with 18.8 million yuan (approximately 357.2 million yen, about 59.53 million yen per project), totaling 28 projects with 95.55 million yuan (approximately 1.81545 billion yen) in support to 11 universities and 7 research institutions.

In the innovative group research programs, the team led by Professor Yuan Yingjin (元英进), Vice President of Tianjin University and academician, established a method for precise repair of genome defects, with some research outcomes published in journals such as Science. This result was selected as one of the top 10 scientific achievements (中国科学十大进展) in China for 2017[103]. The research was performed in joint with Professor Jef D. Boeke of New York

103 XIE Z X, et al. (2017) ““Perfect” designer chromosome V and behavior of a ring derivative”. *Science*, 355(6329):

University. Additionally, Dr. Dai Junbiao from the Shenzhen Institute of Advanced Technology (SIAT) of the Chinese Academy of Sciences developed a method to rapidly and efficiently reconstruct (repair) sequence defects that occur during the synthesis of yeast genomes using the SCRaMbLE method employed in the yeast Sc2.0 project[104].

Within the key programs (重点类项目), the key program (重点项目) supported 12 projects related to the construction of model organisms, microbial drug synthesis, and artificial life systems, with funding of 32.71 million yuan (approximately 621.49 million yen , about 51.8 million yen per project). Additionally, the major program (重大项目) provided support for 5 projects in the aforementioned fields with 29.92 million yuan (approximately 568.48 million yen, about 113.69 million yen per project). Furthermore, 5 projects that came under major research programs (重大研究计划) received funding of 3.25 million yuan (approximately 61.75 million yen, about 12.35 million yen per project), which included research on constructing disease models in non-human primates.

As a significant achievement supported by the key programs, Dr. Qin Zhong Jun of the Center for Excellence in Molecular Plant Sciences of the Chinese Academy of Sciences fused 16 chromosomes of yeast, creating the first eukaryote with a single linear chromosome (SY14 yeast), which was published in Nature Protocols in 2019[105]. This established a functional chromosome fusion method using CRISPR-Cas9, allowing for the design of novel chromosomes, chromosome fusion, and functional verification within 18 days. Additionally, although slightly older in 2016, Dr. Qiu Zilong's team from the Center for Excellence in Brain Science and Intelligence Technology of the Chinese Academy of Sciences established an autism animal model in non-human primates, with some results of this research published in Nature[106]. Besides the above, NSFC funding projects include international joint research support programs, which are omitted in this section.

Thus, NSFC funding supports basic research in synthetic biology, and is not limited to applied fields, enhancing the momentum for creating innovation in China.

Although this research did not gather comprehensive information, as examples of non-NSFC funding, information on "Synthetic Biology" key special projects approved by the Ministry of Science and Technology in fiscal year 2021, as well as projects in the green bio-manufacturing field that solicit research and development using synthetic biology techniques, is organized in Appendix Table A-4, according to "Several Opinions on Improving and Strengthening the Management of Central Financial Research Projects and Funds" by the State Council, including "Notice on Deepening the Management Reform Plan of the Central Financial Science and Technology Plan (Special Projects, etc.)" and "Interim Measures for the Operation of National Key Research and Development Projects." For green bio-manufacturing, the 2022 call for proposals is seeking innovative proposals from young researchers under the category of "bounty system (揭榜挂帅)", with a funding of 35 million yuan (about 665 million yen) for large projects over three years. Fields for which proposals are being accepted include reduced carbon emissions through bioenergy and the development of core technologies in energy-saving production processes.

104 Wei Liu, et al. (2018) "Rapid pathway prototyping and engineering using in vitro and in vivo synthetic genome SCRaMbLE-in methods", *Nature Communications*, 9(1): 1936.

105 SHAO Y, et al. (2019) "Creating functional chromosome fusions in yeast with CRISPR-Cas9" *Nature Protocols*, 14(8): 2521-2545.

106 LIU Z, et al. (2016) "Autism-like behaviours and germline transmission in transgenic monkeys overexpressing MeCP2", *Nature*, 530(7588): 98-102.

2.2.5 Main Research Institutions and University R&D Trends

Table 2-6 summarizes the number of papers (articles, reviews, and conference proceedings) as a form of output under the National Natural Science Foundation’s support of R&D projects related to synthetic biology in the National Science and Technology Major Specific Projects and the National Key Research and Development Programs. There is a tendency for a higher ratio of domestic co-authorship than international co-authorship among many universities and research institutions. Fields such as immunology, microbiology, chemical engineering, and chemistry have notable numbers of publications.

Table 2-6 Academic Paper Numbers Output Top 10 Institutions Related to Synthetic Biology in China from 2015-2020[107]

Institution/University Name (Main Paper Writing Organization)	Number of Papers	FWCI	% International Co-Authorship[108]	% Domestic Co-authorship	% Institutional Co-authorship	% Solo
Chinese Academy of Sciences (国家合成生物技术创新中心)	403	1.32	36.9	**58.1**	3.2	1.8
Tianjin University (Ministry of Education 国家合成生物技术创新中心)	159	1.34	19.5	**71.7**	8.2	0.6
Tsinghua University (清华大学合成与系统生物学中心)	141	1.59	32.9	**37.1**	22.9	7.1
Shanghai Jiao Tong University (上海交通大学生命科学技术学院)	139	1.16	**45**	32.5	22.5	0
Jiangnan University (合成与生物胶体教育部重点实验室)	99	1.49	27.3	**61.6**	10.1	1
Peking University (北京大学定量生物学中心)	80	1.48	30.8	**52.3**	16.9	0
Zhejiang University (浙江大学杭州国际科创中心、浙江大学药学院)	76	1.11	**47.5**	39	13.6	0
East China University of Science and Technology (华东理工大学生物反应器工程国家重点实验室)	56	1.52	32.1	**51.8**	16.1	0

[107] M. J. et al. (2021) “An International Comprehensive Benchmarking Analysis of Synthetic Biology in China from 2015 to 2020,” *Chinese Journal of Chemical Engineering*, https://doi.org/10.1016/j.cjche.2021.05.036

[108] “International Co-authorship” is defined as having authors from institutions in two or more countries including China, “Domestic Co-authorship” as having authors from multiple institutions within China, “Institutional Co-authorship” as having multiple authors from the same institution, and “Solo Authorship” as having a single author.

Wuhan University (武汉大学药学院)	52	1.59	30.2	**58.1**	9.3	2.3
Shandong University (山东大学微生物技术国家重点实验室)	48	0.92	30.2	32.6	**34.9**	2.3

In addition to the above institutions, focusing on Guangdong Province and its surrounding provinces and autonomous regions, which have significant science budgets as outlined in section 2.3.2 (connecting China, Hong Kong, and Macao in the "Greater Bay Area"[109]), the following universities and institutions should continue to be of interest going forward.

- The University of Hong Kong (School of Biomedical Sciences)
- Sun Yat-sen University (School of Life Sciences)
- BGI Research (深圳华大生命科学研究院)
- Shenzhen Bay Laboratory (広東生命情報生物医学研究所)
- Xiamen University (School of Life Sciences)
- University of Science and Technology of China (School of Life Sciences and Medicine, Hefei, Anhui Province)[110]

Among the top 10 institutions in China related to synthetic biology publications listed in Table 2-6, the Chinese Academy of Sciences and Tianjin University, as well as Shanxi University, which is close to many chemical industry-related plants and is working towards carbon neutrality, are outlined below for their recent notable research outcomes and initiatives.

(1) Institute of Synthetic Biology, Shenzhen Institute of Advanced Technology (SIAT) of the Chinese Academy of Sciences

SIAT is an institute focused on IT and biotechnology, established jointly by the Chinese Academy of Sciences (providing talent), Shenzhen Municipal Government (providing land and facilities), and The Chinese University of Hong Kong (which proposed the institute). It actively engages in industry-academia collaboration, having partnerships with many companies such as BGI, HUAWEI, and Tencent. Shenzhen city, through initiatives like the Peacock Plan started in 2011 to attract high-level talent from overseas, proactively provides invitations to outstanding Chinese researchers working in the West. In 2017, Professor Jay D. Keasling of the University of California, Berkeley, who succeeded in the biosynthesis of a special malaria drug (artemisinin) using yeast, opened an endowed research lab at SIAT as a visiting professor, aiming to promote the synthesis and commercialization of Chinese herbal medicine resources[111].

Shenzhen city is one of the cities forming the Guangdong (Shenzhen) - Hong Kong - Macao Greater Bay Area (粵

109 At a symposium held in Tokyo on April 9, 2019, Carrie Lam, the Chief Executive of Hong Kong, Ma Xingrui, the Governor of Guangdong Province, and the Director of the Policy Research and Regional Development Bureau of the Macao Special Administrative Region (positions were current at the time of the symposium), visited Japan and introduced the Greater Bay Area plan:

110 Though not located in the Greater Bay Area, these universities are listed as part of the national science center area.

111 SIAT News:http://english.siat.cas.cn/News2017/SN2017/201709/t20170928_183586.html

港澳大湾区), a strategic initiative pushed by the Chinese government. As the first startup area for the national science center, the Guangming District located in the northern part of Shenzhen is constructing an industrial park specialized in synthetic biology. Similar to Japan, in China, the majority of core research equipment and consumables in the field of biotechnology, such as sequencers, PCR, and culture equipment, are imported, leading to high overall costs for procurement, operation, and maintenance, and posing barriers to automation aligned with data-driven and AI-driven digital transformation and the Design/Build/Test/Learn (DBTL) flow. The synthetic biology research facility in the Guangming District adopts red and blue routes (红蓝军路线) as a key technology development strategy. The red route aims for collaboration amongst domestic R&D teams to develop and build control systems for automated robotics arms and centrifuges, starting projects entirely from scratch. The blue route, which uses existing work, is based on absorbing advanced foreign technologies and achieving early construction of platforms through equipment advancement to achieve open platformization. The goal is to have the combined results from both routes produce even greater outcomes[112]. Additionally, a phase 2 plan aims to build platforms for translational research, including cell synthesis and cell function detection. On February 15, 2022, the Shenzhen Institute of Synthetic Biology's Medical Center was opened at the Chinese Academy of Science Shenzhen Hospital in Guangming District, drawing attention as a cutting-edge hub for clinical application research in the area.[113] Furthermore, the area and its vicinity are equipped with various research facilities, such as a brain analysis and simulation center[114] capable of providing a variety of experimental animals, a multiscale imaging center[115], a national supercomputing center[116] contributing to the "D (Design)" of DBTL, and the China National GeneBank (see section 2.2.6) storing a wide variety of genetic information. The aim is to strengthen complementary relationships through mutual exchange between these facilities.

On December 23, 2021, SynBio China 2021 & Engineering Biology Innovation Forum Ⅲ (Guangming Science City 2021) was held, co-organized by the Development and Reform Commission of Shenzhen, the People's Government of Guangming District, Shenzhen, the Chinese Society of Biotechnology's Division of Synthetic Biology, Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences, and DeepTech, among others[117]. This event featured many presentations on the prospects of new industries brought about by synthetic biology, discussions on new technologies such as high-throughput techniques and storage, and the launch of synthetic biology competitions (Synbio Challenges, Synbio Hive). Following this, on January 5, 2022, the "Frontier Forum on DNA Information Storage" was held by the same institute, and the unveiling ceremony of a DNA information storage and industry innovation transformation center (DNA信息存储产业创新转化中心) took place[118]. Research on DNA storage, which is considered a next-generation frontier field that utilizes DNA as a medium for information storage, is attracting

112 张亭，冷梦甜，金帆，袁海, (2022)"合成生物研究重大科技基础设施概述", *Synthetic Biology Journal,* 3(1) 184-194 DOI: 10.12211/2096-8280.2021-077

113 深圳市光明区政府, "深圳合成生物学创新研究院临床医学中心正式落户光明": http://www.szgm.gov.cn/xxgk/tt/content/post_9576684.html. (Accessed December 2022)

114 脑解析与脑模拟重大科技基础设施: http://www.braintechnews.com/nkjhy/20200828/165.html (Accessed December 2022)

115 Established in cooperation between Shenzhen City and Peking University. 多模态跨尺度生物医学成像设施深圳基地（深圳基地）: http://www.ibp.cas.cn/zhxw/2017zhxw/201803/t20180316_4976687.html (Accessed December 2022)

116 国家超级计算深圳中心(深圳云计算中心): http://www.nsccsz.cn/ (Accessed December 2022)

117 Pharmadeer Information Technology Co., Ltd, "中国合成生物学学术年会暨第三届工程生物创新大会・光明科学城2021,": https://www.pharmadeer.com/activity/69979

118 深圳合成生物学创新研究院, "DNA Information Storage Frontier Forum,": http://www.isynbio.org.cn/news-detail.aspx?detail=5687&parm=577

significant attention for trends in development at SIAT and across China.

A recent notable research outcome from SIAT includes the efficient reduction of carbon dioxide and the synthesis of glucose and fatty acids combined with biosynthetic pathways, published in Nature Catalysis in April 2022, and featured on the cover [119]. This work, co-authored by Professor Yu Tao among others, was highlighted in Science and Technology Daily as one of the top ten scientific and technological news stories in China for 2022, laying the groundwork for artificial food synthesis research.

(2) Tianjin Institute of Industrial Biotechnology (TIB) and Tianjin University Biofoundry

TIB (established in 2012) and Tianjin University were approved by the Ministry of Science and Technology on November 8, 2019, to construct the National Synthetic Biology Innovation Center (國家合成生物技術創新中心) in the Tianjin Airport Economic Area. in the same year, TIB joined the Global BioFoundry Alliance (GBA) with the Shenzhen Institute of Advanced Technology (SIAT) Shenzhen Institute of Synthetic Biology, Chinese Academy of Sciences, to lead synthetic biology research in China[120]. The GBA also includes the School of Life Sciences and Biotechnology at Shanghai Jiao Tong University and Zhejiang University. The aforementioned TIB & Tianjin University Biofoundry has established 16 joint ventures with companies such as “Tianjin Ringpu Bio-Technology Co., Ltd.天津瑞普生物技术股份有限公司 (瑞普-TIB Joint Research Laboratory; headquartered in the Tianjin Airport Economic Area manufacturing food, feed, and chemical products)” in the fields of chemical industry, biomedical, and health food, for the rapid commercialization and market deployment of research outcomes[121].

In 2018, Tianjin University received approval from the Ministry of Education for the construction of a frontier science center for synthetic biology (教育部“珠峰计划”合成生物学前沿科学中心) under the “Everest Plan for Basic Research in Higher Education Institutions” (教育部“珠峰计划”合成生物学前沿科学中心). Additionally, in 2019, the construction of a national synthetic biotechnology innovation center, a joint effort between the Chinese Academy of Sciences and the Tianjin Municipal People’s Government, began[122].

According to Dr. Jibin Sun, Deputy Director of TIB, TIB focuses on bioproduction research such as succinic acid, herbal components such as ginseng, and improvements to vitamin-producing strains, stating that “TIB files a patent every three days, with 53% of approved patents being utilized,” highlighting TIBs research and development and also the application of its results in industry through corporate collaboration[123]. Furthermore, TIB has been developing BioFoundry devices since 2012 to automate the process from PCR, plasmid construction, transformation to check. These devices are capable of constructing 2,000 plasmids within two weeks.

A notable research outcome from TIB includes the world’s first artificial synthesis of starch from carbon dioxide, published in Science on September 24, 2021[124]. TIB, in joint research with the Dalian Institute of Chemical Physics, Chinese Academy of Sciences, designed the Artificial Starch Anabolic Pathway (ASAP), using inorganic catalysts to

119 Tingting Zheng et al. (2022) “Upcycling CO2 into energy-rich long-chain compounds via electrochemical and metabolic engineering”, *Nature Catalysis*, Volume 5 Issue 5

120 Nathan Hillson, et al. (2019) “Building a global alliance of biofoundries,” *Nat. Commun*.

121 Tianjin University, “联合实验室”: http://www.tib.cas.cn/cgzh/lhsys/

122 中央人民政府,“国家合成生物技术创新中心核心研发基地在津启动建设”: http://www.gov.cn/xinwen/2019-12/27/content_5464585.htm

123 From a lecture at the Synthetic Biology Frontier Forum held in December 2020.

124 Tao Cai, et al. (2021) “Cell-free chemoenzymatic starch synthesis from carbon dioxide,” *SCIENCE*

reduce carbon dioxide to methanol and enzymes to convert hexoses, achieving starch synthesis through 11 steps. This method of starch synthesis reached a speed 8.5 times faster and an energy conversion efficiency 3.5 times higher than that of corn, demonstrating a higher efficiency of starch synthesis than plants. It was highlighted in the Science and Technology Daily as one of the top ten scientific and technological news stories in China and abroad for 2021.

(3) Shanxi University & Shanxi Institute of Synthetic Biology

Although Shanxi University currently does not have any notable research outcomes, it is attracting attention for its active efforts to link applications to carbon-neutral policies. The "Shanxi Province High-Quality Development 3-Year Action Plan for the New Materials Industry (2019-2021)"[125] outlines action plans for the development of five distinctive new materials, including advanced metal materials, chemical materials, inorganic non-metal materials, cutting-edge new materials, and bio-based new materials.

In July 2020, the "Shanxi Province Hundred Billion-Level New Material Industry Cluster Development Plan"[126] was announced. It outlines a plan to involve local enterprises, universities, and research institutes in a major international new materials science and technology cooperation project, and to encourage foreign companies and research institutions to establish new material research and development centers and incubation facilities for results within the province, aiming to facilitate industry-academia collaboration and societal implementation. In October of the same year, a cooperation agreement was signed between the Shanxi Transformation and Comprehensive Reform Demonstration Zone and Cathay Biotech, a unicorn in the field of biomaterials (detailed in the next section). Construction is underway for the Shanxi Synthetic Biology Industry Ecological Park, in collaboration with Shanxi University's Department of Synthetic Biology and the Shanxi Synthetic Biology Research Institute (located in Donghuangshui Town, Yangqu County, Taiyuan, Shanxi Province)[127, 128].

CathayBiotech has established the world's first systematic synthetic biology base to promote the development of a bio-based new material industry aimed at replacing petroleum products. It is carrying out ten projects including the production of bio-based pentanediamine (annual production capacity of 500,000 tons), bio-based polyamide (annual production capacity of 900,000 tons), and long-chain dibasic acids (annual production capacity of 80,000 tons). Based on the "2022 Action Plan for the Synthetic Biology New Materials Industry in Shanxi Province"[129] notification by the Shanxi Provincial Department of Industry and Information Technology on February 22, 2022, it also aims to develop new biodegradable plastic technologies, such as pelletizing calcium carbonate and biodegradable resins, as well as develop biopesticides.

125 山西省工业和信息化厅主办, "关于印发《山西省新材料产业高质量发展三年行动计划（2019-2021）》的通知,": https://gxt.shanxi.gov.cn/zfxxgk/zfxxgkml/cl/202110/t20211018_2708027.shtml

126 "山西发布千亿级新材料产业集群培育行动计划,": http://www.shanxi.gov.cn/yw/sxyw/202007/t20200715_827936.shtml

127 JST Science Portal China, "Clothes made from corn and sorghum arrive," September 8, 2021: https://spc.jst.go.jp/news/210902/topic_3_01.html

128 山西省転換型総合改革実証区管理委員会, "王一新在山西合成生物产业生态园调研," https://zgq.shanxi.gov.cn/xmjs/202112/t20211222_4196504.shtml (Accessed January 2022)

129 Shanxi Provincial People's Government, "Shanxi Province Synthetic Biology New Materials Industry 2022 Action Plan," February 22, 2022: http://www.sxzhb.gov.cn/onews.asp?id=58057&owen1=%CD%B6%D7%CA%D6%B8%C4%CF

2.2.6 Trends in Major Industries

In 2020, China accounted for 30% of the synthetic biology market in the Asia-Pacific region. It is forecast to grow from 570 million US dollars (about 70.1 billion yen) in 2021 to 2.355 billion US dollars (about 289.6 billion yen) by 2026, with a compound annual growth rate (CAGR) of 32.8% during the period.[130] The entire biotechnology-related industry in China is being propelled by policies such as “Made in China 2025” and “Healthy China 2030”[131]. For example, the presence of foreign companies in China is expanding everywhere from basic research to industrial deployment, such as the establishment of bases and factories in Shanghai and Hangzhou by foreign companies like American Thermo Fisher Scientific, the opening of a logistics hub by the British Agilent Technologies, and the establishment of an accessible partnership for genome editing tools with Germany’s Merck KGaA and Tongji University (Shanghai).

At present, companies related to synthetic biology in China are biased towards manufacturing. Here, two of these companies, which are among the top in terms of operating profit in China, are introduced as a benchmark. Although this expression may be a cliche, the key to the success of bio-manufacturing lies solely in “strain design and construction” and “scaling up the fermentation process.” The former depends on theoretical research and basic research, while the latter depends on applied research related to the fermentation process. This section will not go into details, but Cabio Biotech (Wuhan) Co.[132], Shandong Jincheng Pharmaceutical Group Co., Ltd., Layn Corp., and Rianlon are also companies active in this field, and were established around 2000[133].

(1) Cathay Biotech (上海凯赛生物技术研发中心有限公司)

Cathay Biotech founded (registered) in 2000 by Xiucai Liu[134], who returned to China from the United States, specializes in bio-based enzyme preparations and polyamide production. Headquartered in Zhangjiang Hi-Tech Park, Pudong, Shanghai, the company aims to develop the bio-based green new materials industry using n-alkanes, a by-product of petroleum, as raw materials and producing long-chain dibasic acids through microbial fermentation. Recently, it has been advancing the clustering of biological production bases in collaboration with the Shanxi provincial government. The relationship between the company and Shanxi Province is deep. In a prospectus for a loan of 830 million yuan (about 15.77 billion yen) obtained from Lu’an Group (a major coal company in Shanxi Province) in 2015, the Shanxi Provincial Finance Bureau and the Shanxi Provincial State-owned Assets Supervision and

130 Markets and Markets, “Synthetic biology market - Global forecast to 2026,” 2021.

131 “Healthy China 2030” is a policy published by the State Council and the Central Committee of the Communist Party of China in 2016, aiming to align the quality standards of domestic medical devices with international standards by 2030 and enhance manufacturing capabilities of high-end domestic medical devices. “Made in China 2025” is a policy published by the State Council in 2015, aiming to elevate China in the manufacturing industry’s value chain through productivity improvements and to make innovation the driving force of economic growth.

132 A biotechnology company established in Province in 2004, specializing in the biosynthesis of β-carotene and the production of omega-6 polyunsaturated fatty acids like Carbito® ARA (arachidonic acid) and selling products such as infant formula milk powder.

133 2023年合成生物学行业深度报告 合成生物学是21世纪最值得关注的行业之一、中信证券、2023年2月: https://www.vzkoo.com/read/20230201f2b8010e3eefb66ef3aa72be.html

134 Liu, born in Anhui Province, obtained his master’s degree from the University of Science and Technology of China and his PhD in Chemistry from the University of Wisconsin-Milwaukee. After conducting postdoctoral research at Yale University and Columbia University, he worked as a senior researcher at Sandoz Pharmaceuticals, where he was involved in drug development. He returned to China in the 1990s where he contributed to the vitamin C industry. He is also an American citizen.https://www.nytimes.com/2011/12/08/business/an-entrepeneurs-rival-in-china-the-state.html

Administration Commission were reported to hold 20.30% of the shares through Shanxi Science Park Investment and Lu’an Group. Cathay Biotech was listed on the Shanghai Stock Exchange STAR Market in August 2020. From the first to the third quarter of 2022, Cathay Biotech achieved an operating profit of 1.838 billion yuan (about 34.9 billion yen), an increase of 4.8% compared to the previous year.

(2) Anhui Huaheng Biotechnology (安徽華恒生物科技股份有限公司)[135]

Huaheng Biotechnology, established in Anhui Province in 2005 by Heng Hua Guo and others, specializes in the production of amino acids, vitamins, and other products using synthetic biology methods. It is headquartered in Hefei City, Anhui Province, with Dongzhu Zhang as the managing director. The company produces a wide range of raw materials used in food additives, health foods, feed, and many other fields, such as alanine (L-alanine, DL-alanine, β-alanine), L-valine, D-calcium pantothenate, and arbutin (α-arbutin, β-arbutin) In 2021, its production of L-valine products through anaerobic fermentation increased, contributing significantly to revenue and profit. In 2022, from the first to the third quarter, it achieved an operating profit of 984 million yuan (about 18.7 billion yen) compared to the same period last year.

Leading the company in science-based product development and production, and research and development is Dr. Xueli Zhang[136], who has served as a director of the company since November 2013 and as Chief Scientist since January 2016. Young engineers of Dr. Zhang’s generation, such as Siqing Tang, who obtained a bachelor’s degree in bioengineering from Hefei University, are among the executive management and have established long-term cooperative relationships with research institutions such as the Tianjin Institute of Industrial Biotechnology, Chinese Academy of Sciences, Shanghai Institute for Biological Sciences, Chinese Academy of Sciences, and the Institute of Microbiology, Chinese Academy of Sciences (Beijing).

2.2.7 Other related trends:

(1) Genetic Database Development

The China National GeneBank (CNGB), established in Shenzhen by the National Development and Reform Commission in 2011 (opened in 2016), is China’s first national-level gene bank. It consists of three banks - a Biorepository, a Bioinformatics Data Center, and a Living Biobank - and two platforms, a Digitalization Platform and a Synthesis and Editing Platform, at its core, with the China National GeneBank DataBase (CNGBdb) databasing this information. China is said to possess the greatest number of genomes in the world.

At CNGB, the George Church Institute of Regenesis, named after Professor George Church of Harvard Medical School, who has recently attempted to revive the woolly mammoth using the CRISPR system, was established in 2017

135 「安徽华恒生物科技股份有限公司」首次公开发行股票并在科创板上市招股说明书，福建省福州市湖东路 268 号：http://file.finance.sina.com.cn/211.154.219.97:9494/MRGG/CNSESH_STOCK/2021/2021-4/2021-04-16/7052638.PDF

136 Dr. Xueli Zhang, born in 1981, obtained his PhD from Shanghai Jiao Tong University and conducted research on microbes at the University of Florida and the Tianjin Institute of Industrial Biotechnology, Chinese Academy of Sciences. In 2017, he received the 14th Tianjin Youth Science and Technology Award, and he has obtained 21 Chinese patents, and 7 international patents, including those for genetically engineered bacteria that produce DL-alanine, and a method for producing DL-alanine using these bacteria (patent specification 2016-503650, among others). https://baike.baidu.com/item/%E5%BC%A0%E5%AD%A6%E7%A4%BC/24278992#reference-[1]-24721243-wrap(As of December 2022)

in collaboration with China's BGI Shenzhen. It conducts research in synthetic biology and genome editing, including efficient DNA data storage methods and the synthesis of E. coli with 57 codons[137].

The National Genomics Data Center (NGDC)[138], one of the centers of the China National Center for Bioinformation (CNCB) established in 2019, has focused on collecting genome data and publishing sequences of SARS-CoV-2 since the outbreak of COVID-19. Originally aimed at collecting and publishing large-scale genomic analysis information related to precision medicine and biodiversity, it systematically organizes resources such as raw data and metadata, genomes and mutations, gene expression, non-coding RNA, epigenomics, single-cell omics, biodiversity and biosynthesis, and health and disease. Additionally, its integrated database for aging research, Aging Atlas, allows for the search of epigenomics and metabolomics data related to humans, mice, rats, and rhesus monkeys. It also maintains other resources, such as the brain research Brainbase database, introduced as the "Monkey Kingdom"[139] in Nature magazine in 2016.

Regulations already in place in 2019 and 2020 manage sharing of genetic resources with foreign partners, including biological samples like organs, tissues, and blood that are directly linked to producing DNA information. However, new regulatory guidelines proposed in March 2022 indicate this management will be further strengthened. Some researchers are concerned that such regulatory strengthening could, at the very least, affect international cooperation in this field[140].

(2) Moves to Publish Science and Technology Journals

To prioritize quality over quantity and correct the tendency to rely on foreign journals, the government announced the "China Science and Technology Journal Excellence Action Plan"[141] to nurture domestic journals. The first phase (2019-2023) of the Plan[142], jointly announced in 2019 by the China Association for Science and Technology, the Ministry of Education, and the Ministry of Science and Technology, defined seven categories including (1) leading journals, (2) key journals, (3) mid-sized journals, and (4) high-quality new journals, along with programs to nurture journals. Progress with nurturing domestic journals bearing the name of synthetic biology is gradually progressing. In 2019, support was decided for 280 journals (180 in English, 100 in Chinese), with a total of about 200 million yuan per year being provided, and in 2020 and 2021, 30 journals per year were supported in the high-quality category. In the field of synthetic biology, "Synthetic and Systems Biotechnology," launched by the Chinese Academy of Sciences in July 2020, has been recognized as a high-quality new journal (高起点新刊). On December 12, 2020, Chemical Industry Press, the Biological Societies of China, and SDIC Biotech Investment Co., Ltd. collaborated to launch the bimonthly Synthetic Biology Journal. The publication aims to be an international top and flagship journal of synthetic biology in China, and is a renaming of the former "Biotechnology & Business" of the China Biotechnology. The

137 At the 12th International Conference on Genomics (ICG-12) in 2017: https://bgi-australia.com.au/news-1/f/george-church-institute-of-regenesis-in-cngb?blogcategory=2017

138 NGDC: https://ngdc.cncb.ac.cn/

139 David Cyranoski. (2016) "Monkey kingdom", *Nature* vol 532, pp300–302 : https://www.nature.com/articles/532300a

140 Smriti Mallapaty. (2022) "China expands control over genetic data used in scientific research", *Nature*: https://www.nature.com/articles/d41586-022-01230-z

141 中央人民政府，"培育世界一流科技期刊 四部门联合发文推动科技期刊改革发展" 2019年8月19日: http://www.gov.cn/xinwen/2019-08/16/content_5421699.htm

142 教育部、中国科学技術協会，"关于组织实施中国科技期刊卓越行动计划有关项目申报的通知" 2019年8月19日: http://www.moe.gov.cn/s78/A16/tongzhi/201909/t20190927_401259.html.

journal is supported organizationally and financially by BGI (Shenzhen 華大基因), Xuzhou Medical University (Jiangsu Province), Twist Bioscience (USA), AMYRIS (USA), Tsingke Biotechnology Co. Ltd., and others. At the Frontiers in Synthetic Biology Forum held concurrently with the journal's first editorial meeting in December 2020, renowned Chinese researchers presented their outlooks for the field. In particular, Dr. Tan Tianwei, President of Beijing University of Chemical Technology and an academician of the Chinese Academy of Engineering, emphasized the need for innovation in response to American export restrictions on biotechnology and the transformation of the chemical industry towards achieving carbon neutrality (dual carbon goals) in his lecture titled "Green Biomanufacturing (緑色生物製造)." He also pointed out the importance of green processes while referring to the closure of chemical companies in Shandong and Jiangsu provinces.

2.3 India

The Indian government set a target in its "Science, Technology, and Innovation Policy 2013"[143] to rapidly achieve 2% of GDP in total R&D investment. This goal was expected to be achieved by 2018 if private enterprise investment proceeded smoothly. In reality, in 2018, government investment was 0.41% and private investment was 0.24%, totaling 0.65%, meaning this goal was not close to being met. It is not easy to obtain the latest total R&D investment figures. However, according to statistics released by the Ministry of Science & Technology (MoST)[144], it was 1.2384 trillion rupees (about 2.2043 trillion yen) in 2018-19, showing an 8.8% increase from 1.1382 trillion rupees (about 2.026 trillion yen) in 2017-18. Contributions from private companies increased from 32.1% in 2010-11 to 36.8% in 2017-18.

Although investment in the field of synthetic biology is unclear, the budget for the Department of Biotechnology (DBT) under the Ministry of Science & Technology is, as an initial budget for the fiscal year 2021, 35.02 billion rupees (about 62.3 billion yen)[145], and for the fiscal year 2022, 25.81 billion rupees (about 45.9 billion yen)[146], indicating that infrastructure for vaccine manufacturing and related pharmaceutical R&D is being established due to the influence of COVID-19, and the biotechnology-related budget is gradually expanding.

This chapter discusses policies, R&D, and industrial trends related to biotechnology, including synthetic biology, in India.

The government has positioned biotechnology, from the perspective of COVID-19 vaccine manufacturing, as part of the "Atmanirbhar Bharat Abhiyaan" (Self-Reliant India Campaign)[147]. The Campaign is an economic stimulus plan aimed at further opening up the Indian economy for the promotion of the "Make in India" policy advocated by Prime Minister Modi. It aims to more closely involve India's manufacturing with international partners to make it more

143 Science, Technology and Innovation Policy, Government of India, http://dst.gov.in/sites/default/files/STI%20Policy%202013-English.pdf

144 RESEARCH AND DEVELOPMENT STATISTICS 2019-20, GOVERNMENT OF INDIA, MINISTRY OF SCIENCE & TECHNOLOGY, DEPARTMENT OF SCIENCE & TECHNOLOGY, NEW DELHI-110016 (INDIA), December 2020: https://dst.gov.in/sites/default/files/Research%20and%20Deveopment%20Statistics%202019-20_0.pdf

145 2022-2023 budget, Indian Finance Ministry: https://www.indiabudget.gov.in/doc/eb/sbe90.pdf

146 On February 1, 2022, Finance Minister Nirmala Sitharaman announced the budget for India for the fiscal year 2022. Although the budget increased by 13.3% from the previous year, the DBT budget decreased by about 10 billion rupees. The budget focused on public investment in infrastructure (increased budget for the Ministry of Railways and the Ministry of Road Transport & Highways) and is estimated to be adjusted based on the DBT's budget implementation for the fiscal year 2021 (about 29.6 billion rupees).

147 INVEST INDIA: https://www.investindia.gov.in/ja-jp/%20atmanirbhar-bharat-abhiyaan

globally competitive, sublimate India's consumption and production into the global supply chain, foster resilience, and provide opportunities that include both investment and technology[148]. Through the positioning of this policy, the government has prioritized budget allocation for biotechnology, simplification of procedures, preparation of investor-friendly environments, and cultivation of excellent talent.

India lacks explicit policies focused on synthetic biology, and funding for basic research is not abundant, trailing behind Western nations and Australia in R&D. However, in August 2022, the Ministry of Science & Technology announced a new program by the DBT-Biotechnology Industry Research Assistance Council (BIRAC), the "AMRIT GRAND CHALLENGE," which supports interdisciplinary and high-quality high-risk R&D, including synthetic biology.

India's biotechnology forms an important industrial base in biomolecules, biosystems, bio-manufacturing, and bio-computing, accounting for about 3% of the global biotechnology market, ranking 12th in the world and 3rd in Asia[149]. The industry size was 70.2 billion dollars (approximately 8.6346 trillion yen) in 2020 and 80.12 billion dollars (approximately 9.8523 trillion yen) in 2021, showing an annual growth rate of 14.13%. It is expected to grow at an annual rate of more than 15%, reaching $150 billion (about 18.45 trillion yen) by 2025, accounting for 19% of the global biotechnology market. Currently, the biotechnology industry consists of more than 3,500 startups, however, this is estimated to number 10,000 by 2024/2025. Prime Minister Modi attended "Biotech Startup Expo 2022"[150] in June 2022, a BIRAC 10th anniversary exhibition, showing the government's focus on supporting this field.

India has invested 9 billion rupees (about 16 billion yen) in COVID-19 vaccine development, providing an excellent opportunity for collaboration among scientists, researchers, medical charities, entrepreneurs, and technocrats, with the industry expected to grow from $2 billion (about 246 billion yen) to $5 billion (about 615 billion yen). The Ministry of Science & Technology, Indian Council of Medical Research (ICMR), Defence Research and Development Organisation (DRDO), and private companies have focused on vaccine production, accounting for 50% of the global vaccine demand. This movement is expected to remain a strong element in the development of the biotechnology industry. The 18th G20 meeting is also scheduled to be held in New Delhi in September 2023, with international discussions on health and medical issues also drawing attention.

Thus, India's biotechnology industry is showing remarkable development, with clear governmental policy efforts and active investment by related private enterprises. In regard to synthetic biology, despite the lack of prominent R&D programs, as mentioned above, there is visible activity amongst industry. From the perspective of research and industrial activities promoted by universities and private enterprises, clarification of government policies that take into consideration international safety regulations, is expected, and the government is also working on demonstrating policy direction and specificity.

148 Anil Wadhwa. (2020) "Partnership, a Visionary Approach," India Perspectives, Issue 4 https://www.indiaperspectives.gov.in/en/visionary-approach/ (Accessed September 5, 2022)

149 India Brand Equity Foundation (IBEF) established by the Government of India's Ministry of Commerce and Industry; https://www.ibef.org/industry/biotechnology-presentation

150 Biotech Startup Expo 2022 is an event held on June 9-10, 2022, in New Delhi, commemorating the 10th anniversary of BIRAC's establishment. The event featured 75 startups supported by BIRAC, 75 biotech incubation centers, 21 IITs and universities, and 50 startups supported by the Department for Promotion of Industry and Internal Trade (DPIIT), including domestic and international companies, and facilitated exchanges with researchers from DBT, CSIR, ICAR, DST, IIT, NIPER (National Institute of Pharmaceutical Education and Research), NISER (National Institute of Science Education and Research), and IISER. DST website:

2.3.1 Government Organizations and Structures[151]

The main agencies involved in research and development related to biotechnology, including synthetic biology, in India, as shown in Figure 2-6, fall under the Ministry of Science and Technology (MoST): the Department of Science and Technology (DST), the Department of Biotechnology (DBT), and the Department of Scientific and Industrial Research (DSIR). Other government agencies involved in research and development include the Defence Research and Development Organisation (DRDO), the Ministry of Electronics and Information Technology (MEITY), and the Ministry of New and Renewable Energy (MNRE).

The overall budget for these government R&D institutions has nearly doubled from 265.59 billion rupees (about 464.7 billion yen) in 2009-10 to 480.45 billion rupees (about 855.1 billion yen) in 2017-18. During this period, DST's budget increased from 19.86 billion rupees (about 35.3 billion yen) to 35.27 billion rupees (about 62.7 billion yen), and DBT's budget from 7.27 billion rupees (about 12.9 billion yen) to 17.72 billion rupees (about 31.5 billion yen)[152]. Overall, DBT has shown more than a doubling of growth, serving as governmental funding to support the market. Subsequently, DBT set the initial budget for the fiscal year 2022 at 25.81 billion rupees (about 45.9 billion yen), of which, 13.1 billion rupees (about 23.3 billion yen) for biotechnology research and development budget and 3.6 billion rupees (about 6.4 billion yen) for industry and entrepreneurship support are planned to be provided in the fiscal year 2022.[153]

The office of the Principal Scientific Adviser (PSA) and its secretariat were established under the Prime Minister as a policy advisory body in 1999, with Dr. Ajay Kumar Sood currently serving as the PSA. Additionally, the "Prime Minister's Science, Technology, and Innovation Advisory Council (PM-STIAC)" has been established under the Prime Minister's Office and is chaired by the PSA. It handles policies on science, technology, and innovation, and coordination and adjustment among ministries. Professor Krishnaswamy VijayRaghavan, who served as the third PSA (from April 2018 to April 2022), was the former director of DBT.

In addition, the Ministry of Chemicals and Fertilizers (MoC&F)'s Department of Pharmaceuticals (DoP) formulated "Pharma Vision 2020." The government is taking the lead in making India a leading country in pharmaceutical and medical device innovation by establishing world-class infrastructure, promoting pharmaceutical R&D with international competitiveness, and supporting ventures in both public and private research.

151 Mainly from Synthetic Biology Market-Global Forecast to 2026.

152 RESEARCH AND DEVELOPMENT STATISTICS 2019-20, GOVERNMENT OF INDIA, MINISTRY OF SCIENCE & TECHNOLOGY, DEPARTMENT OF SCIENCE & TECHNOLOGY, NEW DELHI-110016 (INDIA), December 2020: https://dst.gov.in/sites/default/files/Research%20and%20Deveopment%20Statistics%202019-20_0.pdf

153 On February 1, 2022, Finance Minister Nirmala Sitharaman announced the budget for India for the fiscal year 2022. Although the federal budget increased by 13.3% from the previous year, the DBT budget decreased by about 10 billion Rupees. This was due to a focus on public investment in infrastructure (increased budget for the Ministry of Railways and the Ministry of Road Transport & Highways).

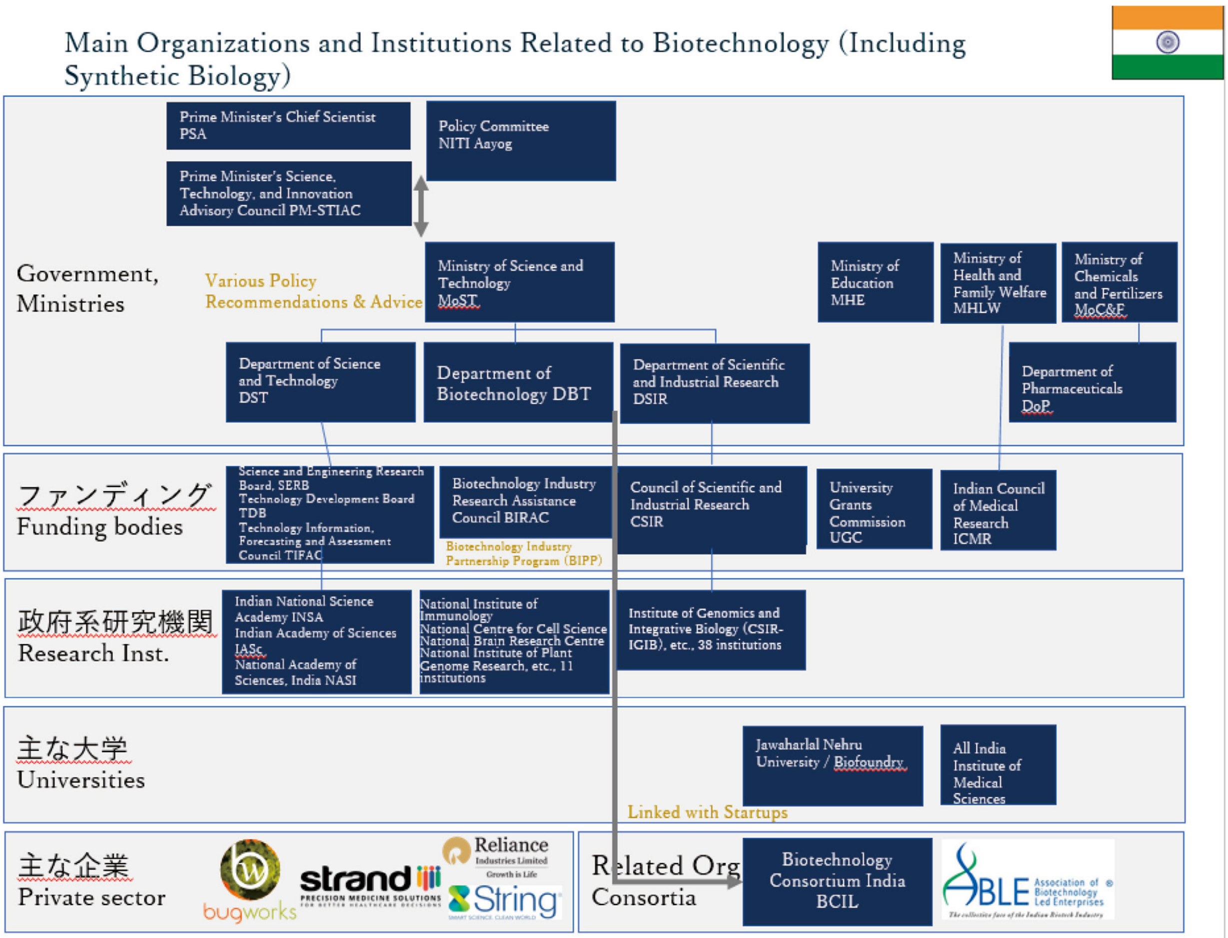


Figure 2-6 Main organizations and institutions related to biotechnology (including synthetic biology)[153]

Below are the details of the main ministries and funding agencies related to biotechnology in India.

(1) Department of Science and Technology (DST)

Established in 1971 under the Ministry of Science and Technology, DST organizes, coordinates, and promotes India's activities related to science and technology. DST's main tasks include formulating policies related to science and technology, assisting the Cabinet Scientific Advisory Committee, promoting science and technology by focusing on specific issues in emerging areas, coordinating with cross-sectoral science and technology-related organizations, financial support for technological surveys and development, and support through grants to scientific research institutions and scientific associations. Major policies like STP (2003) and STIP (2013)[155] were also compiled based on coordination with relevant administrative bodies involved with DST. Under DST, there are several bodies and research institutions, including the Science and Engineering Research Board (SERB), and three natural science academies: Indian National Science Academy (INSA), Indian Academy of Sciences (IASc) founded by Nobel laureate C. V. Raman, and National Academy of Sciences India (NASI). SERB is a research funding agency with the mission of

154 DST and DBT, like ICAR, CSIR, DRDO, and ICMR, have funding functions, but here they are classified into the category of ministries.

155 STI policies will be discussed later under "Science, Technology, and Innovation Policy."

promoting basic research in the fields of science and engineering and providing financial support to researchers and institutes. In 2009, in response to the need for rapid decision-making on research challenges and demands from the scientific and technological system, a bottom-up type of research support was established. This support system aims to provide grants based on the scientific curiosity of researchers and to support challenging research. The DST director serves as the chairperson, with other government officials and renowned scientists as members.

DST’s main support program is the INSPIRE program (Innovation in Science Pursuit for Inspired Research Programme), aimed at early-stage support for young researchers, providing scholarships for higher education, and ensuring research career formation.

(2) Department of Scientific and Industrial Research (DSIR)

Established in 1985, DSIR aims to develop, utilize, and transfer proprietary technologies. That is, it supports the promotion of R&D by industry, the development of commercial potential by SMEs, the early commercialization of laboratory-level outcomes, and enhancement of technological management capabilities in industry. Through the National Research Development Corporation (NRDC), it forms a relationship of technology transfer between scientific research labs and industry and promotes investment.

DSIR houses the Council of Scientific & Industrial Research (CSIR), India’s largest R&D organization established in 1942 to return the outcomes of science and technology to the nation. The CSIR structure has the Prime Minister as the chairman and the Minister of Science and Technology as the vice-chairman. Under its umbrella are 38 independent research institutes, among which approximately ten are related to biotechnology. These include the Institute of Genomics and Integrative Biology (CSIR-IGIB, Delhi), the Centre for Cellular and Molecular Biology (CSIR-CCMB, Hyderabad), the Central Drug Research Institute (CSIR-CDRI, Lucknow), the Central Food Technological Research Institute (CSIR-CFTRI, Mysuru), the Indian Institute of Chemical Biology (CSIR-IICB, Kolkata), the Institute of Integrative Medicine (CSIR-IIIM, Jammu), the Institute of Microbial Technology (CSIR-IMTECH, Chandigarh), and the National Botanical Research Institute (CSIR-NBRI, Lucknow), among others.

DSIR also has a system where certified organizations (e.g., SCPL[156]) assist companies in applying for funding and tax incentives. This system primarily targets programs of the Biotechnology Industry Research Assistance Council (BIRAC), mentioned later. To receive public support (financial measures, preferential treatment, etc.), a form of government certification called the Industrial R&D Promotion Programme (IRDPP) is required.[157] Organizations or systems certified under this program receive support from Scientific and Industrial Research Organizations (SIRO)[158]. Under the SIRO system, organizations like universities are recognized for activities that expand knowledge in natural sciences, applied sciences, agriculture, medical, and social sciences under a governance system with clear objectives. Organizations certified in this way can benefit from tax exemptions on the import of scientific research equipment and relaxed procedures. Given the impact of COVID-19, DSIR has extended the SIRO certification.

[156] SCPL (Scinnovation Consultants Pvt. Ltd.) is a private company established in 2005. It provides support on IP strategy, tax incentives, etc., for startups, and also assists in accessing funding for research and development. (Reference: Accessed on the 9th of https://www.scinnovation.in/ (Accessed on September 9, 2022)

[157] IRDPP Details:https://www.indiascienceandtechnology.gov.in/programme-schemes/research-and-development/industrial-rd-promotion-programme-irdpp

[158] SIRO System Details:https://www.mondaq.com/india/patent/1108600/application-process-of-getting-siro-recognition

(3) Department of Biotechnology (DBT)

DBT is an agency that promotes biotechnology research oriented towards agriculture, environment, and industrial applications. It was established in 1986 by then Prime Minister Rajiv Ratna Gandhi, in response to global trends in biotechnology, as an independent department within MoST. It supports research and development and manufacturing, oversees its subordinate independent research institutes, promotes industry-academia collaboration, develops human resources, and establishes infrastructure facilities.

The National Biotechnology Board (NBTB) advises on the formulation of long-term outlooks and the selection of priority areas for DBT’s policy formulation. NBTB is also tasked with nurturing programs in emerging fields and strengthening unique human capabilities. DBT announced the first National Biotechnology Development Strategy in 2007 and has been updating this strategy approximately every five years since 2015 (see section 2.2.2(2)). The latest version of the Strategy is for 2021-2025[159].

The budget for DBT for the fiscal year 2022 was set at 25.81 billion rupees (about 45.9 billion yen) in the federal budget established in February 2022, allocated for basic infrastructure, genetic engineering, bioinformatics, agricultural biotech, skill training, etc.[160]

Below are the main programs and systems managed by DBT.

・Undertaking Nationally Relevant Technology Innovation/Atal Jai Anusandhan Biotech Mission (UNaTI)

A program initiated by DBT on its foundation day in February 2019, aiming to reform the sectors of health, agriculture, and energy over five years. It includes the following missions[161].

- ➡GARBH-ini: aims to promote maternal and child health and develop tools for predicting preterm birth. GARBH-ini (Interdisciplinary Group for Advanced Research on Birth Outcomes - DBT India Initiative)[162] is an interdisciplinary collaboration program started in 2014, conducting cohort studies on pregnant women at a citizen’s hospital in Gurugram, Haryana.
- ➡Ind-CEPI Mission: Supports Indian vaccine development in collaboration with the international initiative Coalition for Epidemic Preparedness Innovations (CEPI) as a measure against infectious diseases through rapid vaccine development. A program management unit was established within the non-profit corporation established by DBT, the previously mentioned Biotechnology Industry Research Assistance Council (BIRAC).
- ➡Anti-Microbial Resistance (AMR) Mission: Ensures rapidity in diagnosis, treatment, and preventive measures against antimicrobial resistant pathogens.
- ➡UNATI Mission Clean Technologies for Swachh Bharat[163]: Identifies ten clean technologies, such as biomethanization, constructed wetlands, bio-toilets, and non-chemical membrane-based water purification, and demonstrates them in various locations across India in collaboration with local stakeholders like

159 DBT (2021), “National Biotechnology Development Strategy2021-2025”, https://dbtindia.gov.in/sites/default/files/NATIONAL%20BIOTECHNOLOGY%20DEVELOPMENT%20STRATEGY_01.04.pdf

160 Indian Biotechnology Industry Analysis: https://www.ibef.org/industry/biotechnology-presentation

161 MoST (2019) “Key missions launched on foundation day of DBT”, https://pib.gov.in/PressReleasePage.aspx?PRID=1566339

162 Garbh-ini (n.d.) “About us”, https://www.garbhinicohort.in/

163 “Swachh Bharat” (Clean India) is a nationwide campaign started by the central government in 2014 to achieve an India without open defecation.

municipalities.

➡Fortified Wheat Nutritional Improvement: Develops protein-rich fortified wheat to contribute to the government’s malnutrition campaign “POSHAN Abhiyan” (Holistic Nutrition) started in 2018.

・Agriculture Biotechnology[164]

A program started to reform agricultural research by incorporating technological advancements and strengthening research infrastructure and talent development in cutting-edge areas. It supports research on the creation of knowledge, development of technologies and products to enhance productivity, improvements in the nutritional value and quality of crops, resilience to abiotic and biotic stress, efficiency in the use of input resources, climate resilience, and biosafety. It covers economically significant crops such as rice, wheat, corn, cotton, cereals, oilseeds, legumes, as well as horticultural crops. Under this program, DBT has supported research and development projects through basic research such as molecular breeding/marker-assisted selection (MAS), identification of QTL/genes, crop quality improvement with added functions like Vitamin A richness, disease (such as bacterial blight) and disaster resistance, international collaborations, and public-private partnerships, revising the system in recent years to meet changing needs from farmers, consumers, and export markets.

・Biotechnology Programme for North Eastern Region[165]

This program targets the North Eastern Region of India, known globally for its threatened biodiversity, to utilize its rich biological resources spread across the ecosystem for further economic development of the region. DBT allocates 10% of its annual budget to promote and enhance biotechnology-related activities in this region, supporting solutions to regional problems and the use of biological resources for regional development. To ensure the program is operated efficiently, the North Eastern Region Biotechnology Programme Management Cell (NER-BPMC) was established at the DBT Institute of Life Sciences (DBT-ILS) in Bhubaneswar.

The establishment and operation of biotechnology parks/incubators are mentioned as a major initiative of DBT for promoting the conversion of research outcomes into products and services Here, under the National Biotechnology Parks Scheme[166], scientists and SMEs carry out technology incubation, technological demonstration, and pilot plant studies to promote the commercial development of biotechnology DBT has established 9 biotechnology parks in India. These parks include ecosystems that support startups to develop beyond the incubation stage and provide further assistance in scaling up.

In addition to supporting biotechnology parks, DBT has been actively establishing centers specialized in energy research aimed at achieving carbon neutrality in recent years. Currently, it has established the DBT-ICT Centre for Energy Biosciences (DBT-ICT-CEB, Mumbai), established jointly with the CSIR National Chemical Laboratory (ICT), the DBT-IOC Centre for Advanced Bio-Energy Research, relocated from Mumbai to Faridabad near New

164 DBT (n.d.) “Agriculture & Plant Sciences”, https://dbtindia.gov.in/schemes-programmes/research-development/agriculture-animal-allied-sciences/agriculture-biotechnology

165 DBT (n.d.) “North East Region (NER)”, https://dbtindia.gov.in/scientificdecisionunits/ner
Note: This page was updated on March 21, 2022, with content changed to “Under Preparation,” and the information referred to at the time of preparing this document was deleted.

166 Biotechnology Park Plan:https://dbtindia.gov.in/sites/default/files/guidelines_biotech_Park_0.pdf

Delhi, in collaboration with Indian Oil Corporation (IOC), and the International Centre for Genetic Engineering and Biotechnology (ICGEB, Delhi). These institutes focus on biofuel research, including biodiesel, bioethanol, biobutanol, and biohydrogen production.

Taking an overhead look at this series of initiatives by DBT, although there are few institutions explicitly conducting synthetic biology, biotechnology research in India revolves around research clusters established within the country. These clusters integrate the research capabilities of core facilities and core services from academies and promote startup incubation. They also integrate core facilities and services such as genome analysis, gene phenotype analysis, genomics, and proteomics analysis. This structure is how the government has formed its platform for innovation. Of note, DBT signed a Memorandum of Understanding with the Indian Angel Network in August 2017 to create an environment in which startups can easily receive investment.

From a synthetic biology perspective, DBT launched a joint funding scheme in 2018 to promote research cooperation with the Finland Academy, known for its active biofuel research. In the same year, DBT launched training courses aimed at providing a fundamental understanding of bioengineering for aquatic and marine organisms, research that serves as a foundation from academia to industry, the practice of computational and experimental synthetic biology, and knowledge on ethics/biosafety in relation to synthetic biology[167].

(4) Biotechnology Industry Research Assistance Council (BIRAC)

BIRAC, a non-profit organization established by DBT, conducts strategic research and innovation, and addresses the development needs of products required by India. BIRAC’s vision is to nurture and strengthen the strategic research and innovation capabilities of India’s biotechnology industry, aiming especially for SMEs and startups to produce affordable products addressing broad societal needs, contributing to constructing a bio-economy.

BIRAC has supported over 3500 startups, 600 technologies/products, established 74 bio-incubation and pre-incubation centers, supported 344 academic organizations, with a total support amount of 40 billion rupees (about 71.2 billion yen)[168].

2.3.2 Major Policies and Key Issues

According to the Science, Technology, and Innovation Policy (STIP2013), India’s science and technology policy aims to form a Science, Research and Innovation System for High Technology-led path for India (SRISHTI), prioritizing critical research in key sectors like agriculture, communication, energy, promoting interdisciplinary research, supporting risk development for SMEs, establishing funds for an inclusive society, and supporting entrepreneurship led by science and technology innovation. Its goal was to increase the total R&D investment to 2% of GDP (1% at the time), increase the number of research personnel (FTE) by 66%, and increase the global share of papers from 3.5% to over 7% by 2020, aiming to be within the top 5 countries globally[169].

167 The DBT training program in SYNTHETIC BIOLOGY, https://syntheticbioindia.weebly.com/dbt-syn-bio-training.html(Accessed on September 24, 2022)

168 From BRIAC website: https://birac.nic.in/

169 India, which produced about 149,000 papers (fractional count) in 2020, ranked 3rd after China and the United States, achieving the plan’s goal. From Global Note Inc.’s website: https://www.globalnote.jp/post-5275.html (Accessed on September 8, 2022)

The draft of the successor plan, Science, Technology and Innovation Policy 2020 (STIP2020)[170], aims to make India the third largest science and technology powerhouse in the world over the next decade, double India’s total R&D investment (GERD) and the number of researchers (FTE) every five years, and have outstanding individuals and organizations receive world-class awards over the next decade. Additionally, the national project formulated in March 2019 includes implementing support for the commercialization of innovations, including automated translation technologies, quantum frontiers, artificial intelligence, biodiversity, electric vehicles, health care, waste utilization, and deep-sea exploration[171]. Various policies are being advanced based on this plan, but here the main policies related to biotechnology, including synthetic biology, have been highlighted, specifically within DBT. Not detailed below are national initiatives related to the industrial application of synthetic biology research, including the National Policy on Biofuels[172] by the Ministry of Petroleum & Natural Gas and the National Biopharma Mission[173] by DBT.

(1) National Biotechnology Development Strategy 2015-2020 (NDBS2015-2020)

In 2000, DBT issued its first document on its vision for the future of biotechnology. In September 2007 it formulated the first National Biotechnology Development Strategy, marking the dawn of India’s biotechnology sector and contributing to the launch of various necessary projects. BIRAC was also established in 2012 after this strategy was formulated, giving momentum to the development of biotechnology in the private sector. However, the full-fledged policy was the National Biotechnology Development Strategy 2015-2020, announced by DBT in December 2015, which was drafted with the help of experts from academia, government, and industry. It broadly covers necessary measures from education to the promotion of bioscience research and commercialization, establishing the following fundamental principles in the field of biotechnology:

1. Securing an excellent workforce and leadership.
2. Invigorating the intellectual environment along with the growing bio-industry.
3. Enhancing the potential for research in fundamental, academic, and interdisciplinary science.
4. Promoting new, purpose-driven research.
5. Focusing on biotechnology as a tool for comprehensive development.
6. Advancing technology-driven innovation, transfer capabilities, and commercialization.

170 The drafting of STIP2020 started in October 2019, with a schedule laid out from public and expert opinion collection in Track I in May 2020 to reporting to the Prime Minister’s Office in Track IV in November 2021. As of early 2023, there is no information on the final policy being published.
https://thesciencepolicyforum.org/initiatives/science-technology-and-innovation-policy-stip-2020/

171 For an overview of India’s science and technology policy advancements, see “Overview of Advancing India’s Science and Technology Policy” by Kiyoshi Kurihara, NIISTEP Horizon, 2022, Vol.8. No.2.
https://www.nistep.go.jp/wp/wp-content/uploads/NISTEP-STIH8-2-00296.pdf(Accessed September 25, 2022)

172 Announced by the Ministry of Petroleum & Natural Gas in 2018 and revised in June 2022. This policy aims to promote the production of domestic biofuels and support the reduction of petroleum product imports. From the International Energy Agency (IEA) website:https://www.iea.org/policies/17006-national-policy-on-biofuels-amendment-2022

173 The National Biopharma Mission, approved by the cabinet committee on the economy in 2017, titled “Innovate in India (i3),” aims to accelerate innovation creation through the development of affordable products to improve the country’s health standards and strengthen entrepreneurship support This mission aligns with other national missions such as Make in India and Start-up India. By investing $250 million (approximately 31.7 billion yen), it aims to introduce 5 to 7 types of biopharmaceuticals to the market over the next four years. From the DBT website:
https://dbtindia.gov.in/sites/default/files/uploadfiles/NBM%20WEBSITE-Dr.%20Madhavi_FV.pdf

7. Realizing biotechnology in society with a transparent, efficient, and optimal regulatory system and communication strategy.
8. Engaging in international biotechnology cooperation that nurtures the country’s alliances.
9. Reconstructing governance models to enhance institutional capabilities.

Specific measures include establishing training programs for students, core facilities/equipment, special centers/commercialization centers, and national research institutes such as the National Institute of Pharmaceutical Education and Research, the Interdisciplinary Infection Science Research Centres, and the National Institute of Ocean Biotechnology, proposing the establishment of a knowledge environment. Furthermore, it also focuses on various research areas in bio-design research such as human genome, vaccine development, infectious diseases, clinical, chronic diseases, stem cells & regenerative medicine, implants & diagnostics, and biotechnology.

Synthetic biology is first noted among the basic principles for promoting research in interdisciplinary fields alongside systems biology and nanobiotechnology as an emerging field. Specific measures include strengthening DBT’s support for research aimed at understanding genetic diseases in human genome research, as well as enzymatic research and biofuel-related research.

This strategy emphasizes the importance of securing a public-private partnership, establishing intellectual property rights protection measures, setting up safety regulation measures for genetic use, and enhancing understanding in society. Regarding international cooperation, DBT is planning to expand the cooperation systems that will be required for this, although no special considerations for emerging critical technologies has been observed as of yet. This strategy does not provide financial plans from the government or forecasts on the industrial scale that future biotechnology development may bring.

(2) National Biotechnology Development Strategy 2021-2025 (NDBS2021-2025)[174]

As a successor to the previous development strategy, the National Biotechnology Development Strategy 2021-2025 formulated by DBT in 2021 sets ambitious goals to contribute to a “knowledge and innovation-driven bio-economy” during the target period. Its main strategies are as follows:

- Talent Development: Strengthening production of highly skilled personnel and cutting-edge infrastructure
- UNATI[175] Biotechnology Mission: Aligning with India’s and the world’s priorities
- Aiming for a “Atmanirbhar Bharat (self-reliant India)” through biotechnology: Affordable products and technologies accessible to all
- Leveraging the strengths of strategic partnerships: Domestic and international
- Measures for the future - Building a knowledge base & bringing science to society: Revitalizing the rural sector
- Effective outreach and communication: Building social trust
- Global benchmarks and performance evaluation: Quality control and improvements through metrics

174 From APRC-FY2022-PD-IND03 (provisional translation):https://spap.jst.go.jp/resource/pdf/aprc-fy2022-pd-ind03.pdf

175 UNATI is an acronym for Undertaking Nationally relevant Technology Innovation (Atal Jai Anusandhan Biotech), a mission to address critical issues in India and around the world, such as maternal and child health, antimicrobial drug resistance (AMR), infectious disease vaccines, food, nutrition, and clean technologies.

The National Biotechnology Development Strategy 2021-2025[176] sets a goal to position India’s biotechnology within the top 5 nations globally and become a hub for the world’s biomanufacturing industry, achieving a bio-technology sector economic size of $150 billion (approximately 18.45 trillion yen) by 2025. In the aforementioned strategy, synthetic biology is highlighted as an important field within talent cultivation, UNATI, measures for the future, and policy implementation as outlined below. However, as of now, there are no calls for programs specifically dedicated to synthetic biology.

- Training talent adaptable to strategic fields such as data science, synthetic biology, cell & regenerative medicine, genome editing, artificial intelligence, computational & structural biology, and quantum biology.
- Direct funding for new biological fields and blue-sky research related to synthetic biology, quantum biology, nutrigenomics, personalized medicine, microbiome manipulation technologies, and SDGs.
- Expansion of substantial concentrated investments towards the following priority areas in emerging biotechnology fields and cutting-edge basic research: Personalized medicine, CAR-T technology, genome editing & therapy, CRISPR-Cas, synthetic biology, lipid biology, glycobiology, epigenetics, plant secondary metabolism, marine biology, natural products chemistry, quantum biology, 3D bioprinting, etc.
- Develop guidelines on ethics and the use of synthetic biology and emerging technologies.

In NDBS2021-2025, various targets have been set, including the establishment of a 100 billion US dollar (approximately 12.3 trillion yen) scale international biotechnology manufacturing hub (Biomanufacturing Global Hub) and the expansion of base initiatives such as 125 biotech incubators, 10 technology clusters, 10 biotechnology parks and manufacturing bases, 10 biotech university-industry joint research translational clusters (UNIVERSITY RESEARCH JOINT INDUSTRY TRANSLATIONAL CLUSTER, Biotech URJIT Cluster), and 10 centers of excellence in emerging technologies (CONEs). These targets are being closely watched for future developments.

(Reference) The 12th Five-Year Plan and Synthetic Biology (2011)

Since the first Five-Year Plan (1951-1956), India has been formulating five-year plans as national economic programs, with the latest, the 12th Five-Year Plan, covering 2012-2017 (a 13th Five-Year Plan has not been formulated). During the 12th Five-Year Plan period, the Task Force on Synthetic and Systems Biology Resource Network compiled a report titled “Resource Network for Synthetic Biology and Systems Biology.” to recommend the promotion of synthetic biology and related initiatives by the Indian government[177]. The report emphasizes the potential benefits of synthetic biology in biofuels, biotherapeutics, biosensors, and food & health, hoping for India to strongly promote technology enabling it to become a global leader in this field.

176 DBT (2021), “National Biotechnology Development Strategy2021-2025”, https://dbtindia.gov.in/sites/default/files/NATIONAL%20BIOTECHNOLOGY%20DEVELOPMENT%20STRATEGY_01.04.pdf

177 12th FIVE YEAR PLAN, Report of the Planning Commission Constituted Task Force on Synthetic and System Biology Resource Network, https://dst.gov.in/sites/default/files/3-tsk_ssbrn-report.pdf

In the 12th Five-Year Plan related to DBT, nanoscience, bioscience, and synthetic biology were highlighted under the section on strengthening the biotech industry through collaboration of existing research organizations. These fields are eligible for research funding assistance and strengthened partnership research by DBT. However, the plan had listed a CSIR institute of synthetic biology and systems biology to be established during the CSIR plan period[178], but it appears that this has not been realized.

Even after the formulation of the 12th Five-Year Plan, the parliament has not deliberated on the bill related to the establishment of an independent regulatory authority for biotechnology since 2013, and discussions that could affect research surrounding genetic engineering, which includes synthetic biology, have not progressed[179]. India is facing challenges such as the ban on genetically modified eggplant products and lawsuits against genetically modified grains.

(3) Task Force Report on the Resource Network for Synthetic Biology and Systems Biology[180]

When DST released this report in 2011, synthetic biology and systems biology were still in their infancy in India, and there was no doubt that India’s potential in human resources in this field was untapped. The document states that India, with only a limited number of players such as CSIR’s related institutes, the Indian Institute of Science (IISc), National Centre for Biological Sciences (NCBS), Indian Institute of Technology Kharagpur (IIT-Kharagpur), Bose Institute, University of Kerala, and a few companies, needs a “push” towards synthetic biology, requiring sufficient support from feasible technologies to achieve practical applications. The report’s immediate goal was to build expertise and infrastructure in synthetic biology and systems biology.

India is attempting to lead the world as a protector and supporter of open-source biological platforms by creating the right legal environment where small biotechnology firms can compete with major pharmaceutical and petroleum companies.

The Task Force’s recommendations include capacity building through the establishment of institutions, training centers, and network centers, promoting human resource development, building translational capabilities, developing multimodal and fast-track funding mechanisms, and establishing international cooperation. It also suggests elevating the Task Force to a permanent committee with new members to create domestic documents and coordinate a national network of synthetic biology and systems biology research.

(4) Foresight Paper of Synthetic Biology[181]

Since DBT’s establishment in 1986, India has long lacked consensus on how the government should address synthetic

178 Twelfth Five Year Plan (2012–2017), Faster, More Inclusive and Sustainable Growth, Volume I, 10 May, 2013, https://nhm.gov.in/images/pdf/publication/Planning_Commission/12th_Five_year_plan-Vol-1.pdf

179 “India needs a policy on synthetic biology”, BusinessLine, December 16, 2019, https://www.thehindubusinessline.com/opinion/india-needs-a-policy-on-synthetic-biology/article30322176.ece

180 REPORT OF THE PLANNING COMMISSION CONSTITUTED TASK FORCE ON SYNTHETIC AND SYSTEMS BIOLOGY RESOURCE NETWORK (SSBRN) , https://dst.gov.in/sites/default/files/3-tsk_ssbrn-report.pdf

181 Foresight Paper of Synthetic Biology, DBT, https://dbtindia.gov.in/sites/default/files/uploadfiles/2.%20JNU-FLEDGE%20Project%20Report%20on%20synthetic%20biology_updated%2008022022.pdf (Accessed September 22, 2022)

biology, as exemplified by genetic engineering technologies. However, the development of synthetic biology has a history that is over 30 years long, and reducing reliance on petroleum-based products is becoming crucial for building a sustainable and inclusive future. Therefore, it was necessary to clarify what synthetic biology is, its potential applications, and the required regulations. While Indian industry is advancing investments in synthetic biology, there is a lack of regulations and policies concerning this technology, creating a dilemma. The policies to be formulated are expected to define synthetic biology, prioritize research and development in the public sector, guide policy frameworks including intellectual property rights, and regulate environmental and socio-economic issues.

Amidst these circumstances, in December 2019, DBT commissioned a team[182] led by Professor Pawan Kumar Dhar of Jawaharlal Nehru University to analyze the prospects of synthetic biology, with Dr. Syed Shams Yazdani of ICGEB and many researchers participating in the discussion. The project examined the current state and future direction of public and private research and development in this field, the country's promotion policies, domestic and international legal regulations, and strategies for dialoging with the public. The results presented further perspectives for formulating national policies, emphasizing the importance of considering international legal regulatory elements crucial for national policy formulation.

While recognizing synthetic biology as a driver of a new industrial revolution, crucial challenges for India include appropriately evaluating the benefits and risks, accelerating scientific research, and clarifying the Indian government's stance on synthetic biology, conveying its benefits and enthusiasm to the international community. The findings were compiled into the Foresight Paper of Synthetic Biology, and DBT accepted public opinions regarding the matter on its website until March 15, 2022. As of early 2023, no information on the results of these opinions has been released.

(5) Regulations on Biotechnology or Synthetic Biology Safety

The international debate on biotechnology safety regulations began with recombinant DNA research in the 1970s at the Asilomar Conference, and India has been building its domestic system in line with this movement since then. Subsequently, the need for regulations on genetically modified plants or agricultural products emerged, and in the late 1980s, a national biosafety framework was established, with the current regulatory framework being established in 1989[183].

Concerns related to research involving synthetic biology include unintended infections of laboratory personnel, leaks from containment areas of pathogens, lack of certification and validity for laboratories requiring Biological Safety Level BSL2, improper handling of biological waste in drug trials or clinical trials, and intentional release of genetically modified organisms into the environment. India has many BSL level facilities that handle pathogens, and DBT has introduced an application system to confirm the validity of BSL3 or 4 research facilities. However, experts are concerned about the lack of national guidelines and a verification system for BSL research facilities' certification and validity, fearing these issues could constrain research and development and entry into the market

182 Jawaharlal Nehru University serves as India's representative node in the Global Biofoundry Alliance (GBA) as Biofoundry India. Co-directors of Biofoundry India include Professor Pawan Kumar Dhar and Professor Binay Panda, who compiled this report. Project Theme "Policy and Research Planning for Synthetic Biology," Project ID: BT/PBD/26/SP30134/2018: https://www.syntheticbiology.in/_files/ugd/cdb456_136f7cc2a81c4ddda4d7b194ba1b3cea.pdf

183 Regulatory framework for genetically engineered plants in India: http://www.geacindia.gov.in/resource-documents/13_2-Regulatory_Framework_for_GE_Plants_in_India.pdf (Accessed September 22, 2022)

of synthetic biology in India[184]. The Carnegie Endowment[185] report in 2020 also mentioned that while DBT manages safety regulations for BSL3 and 4 facilities, measures for lower-level facilities are insufficient, raising concerns about unintended staff contamination and foreign substances being released into the environment.

Indian legal framework of relevance to this topic includes the 1986 Environmental Protection Act, the Rules for the Manufacture, Use, Import, Export, and Storage of Hazardous Microorganisms, Genetically Engineered Organisms or Cells (known as the 1989 Rules), the 2002 Biological Diversity Act, the 2003 Plant Quarantine Order, the 2006 Food Safety and Standards Act, etc., overseen by the DBT, Ministry of Agriculture and Farmers Welfare, Ministry of Health and Family Welfare, among others. Additionally, under the 1989 Rules, specific procedures are taken within the framework of six regulatory/advisory committees such as the Review Committee on Genetic Manipulation (RCGM) (the secretariat of RCGM is the DBT)[186].

The aforementioned NDBS2021-2025 states that it is necessary to establish a biotechnology regulatory authority through appropriate legislation, which will aim to improve regulatory personnel training, guideline development, and public understanding, as well as improve the regulatory framework including the RCGM mentioned above. In March 2021, at the online Global Bio-India 2021[187], it was stated that India’s previous system needs to be revised in light of Western regulatory frameworks, and as seen through the foresight paper on synthetic biology (2022), this is an important issue at present.

(6) Pharmaceutical Industry-Related Research and Development Innovation Policy

The pharmaceutical industry, as already mentioned, plays a significant role in India’s biotechnology-related industrial activities. The Department of Pharmaceuticals of India, under the Ministry of Chemicals and Fertilizers, announced a policy draft for the pharmaceutical and medical device-related research and development innovation sector in October 2021[188]. This policy draft, which was open for comment until November 21, 2021, has a significant impact on India’s pharmaceutical industry, and it is expected that industry movements will become more active based on this policy[189].

The policy draft[190] is to be implemented according to an action plan that defines specific activities, goals, and schedules over the next ten years, with its basic direction being (1) simplification of the regulatory process, (2) acceleration of new drug development and promotion of medical device development innovation, (3) strengthening motivation to invest privately and evaluation of various sources of funding, (4) enhancement of the ecosystem to

184 Synthetic Biology Market-Global Forecast to 2026

185 DECEMBER 09, 2020, “Biological Risks in India: Perspectives and Analysis”, SHRUTI SHARMA, Carnegie India, https://carnegieendowment.org/2020/12/09/biological-risks-in-india-perspectives-and-analysis-pub-83399

186 Review Committee on Genetic Manipulation https://ibkp.dbtindia.gov.in/Registration/Index, https://ibkp.dbtindia.gov.in/Content/Commitee?AspxAutoDetectCookieSupport=1 (Accessed September 22, 2022))

187 Global Bio-India 2021 (hosted by DBT and BIRAC) https://birac.nic.in/webcontent/1651648167_Global_Bio_India_2021_Report.pdf

188 “Draft Policy to Catalyze Research & Development and Innovation in the Pharma - MedTech Sector in India”, https://pharmaceuticals.gov.in/sites/default/files/Draft%20Policy.pdf (Accessed September 23, 2022)

189 “DoP releases draft policy to catalyse R&D and innovation in pharma-MedTech”, Pharma.Biz, Gireesh Babu, New Delhi, Wednesday, October 27, 2021, http://pharmabiz.com/ArticleDetails.aspx?aid=143514&sid=1#:~:text=The%20draft%20policy%20aims%20to,stakeholders%20by%20November%206%2C%202021 (Accessed September 23, 2022)

190 “Centre finalising policy to catalyse R&D and innovation in pharma and med-tech sectors”, PharmaBiz. Com. February 8, 2023. According to this report, the government is currently working on finalizing a policy. http://www.pharmabiz.com/NewsDetails.aspx?aid=156229&sid=1

promote cooperation between industry and academia. Especially in regard to the simplification of the regulatory process, it calls for a joint effort among regulatory bodies to make regulations more innovation-oriented, aiming to eliminate duplications in the regulatory process and clarify timelines, with goals such as halving the approval time for new drugs within the next two years and setting the review period for medical devices within 12 months. In terms of expanding cooperation between industry and academia, it proposes opening up academic infrastructure for industry use and talent development, involving industry representatives in the National Institute of Pharmaceutical Education & Research (NIPER) to strengthen the training of specialists in higher education such as doctoral programs. Furthermore, the draft proposes the establishment of inter-departmental research conferences and innovation hubs to facilitate cooperation between the educational and industrial sectors.

(7) Relation to Economic Security Policy

The government formulated India's National Security Strategy in March 2019. Its goal is to protect India's sovereignty, ensure territorial integrity, secure India's rightful place in the international arena, guarantee a peaceful domestic environment, and create a fair, equal, and prosperous environment for citizens, protecting them and their livelihoods from dangers. At present, it only has a minimal relationship with synthetic biology, but India's security strategy is outlined here for reference.

In terms of economic security, it emphasizes the importance of financial and fiscal policies, ensuring the reduction of vulnerabilities in the Indian economy, and establishes a national "Digital Security Organization" to protect government and civilian public facilities, power, banking, communication, computer, and internet environments. Regarding technological development, it sees the advancement of AI, robotics, quantum computing, etc., as potentially threatening the safety of the economy and public life, pointing out threats in cyberspace and advocating for appropriate protective measures. It also urges measures to enhance energy security, defense industry infrastructure, and measures against nuclear, space, and cyber technologies.

However, this security policy does not include appropriate measures for technological cooperation, technology trade, and international research and development cooperation in advanced fields that take into consideration the harsh international environment surrounding advanced emerging technologies. In August 2022, the Ministry of Electronics and Information Technology's Emerging Technologies Division published a list[191] of emerging technologies promoting the adoption of advanced technologies with significant socio-economic impact, focusing on information technology, AI, robotics, IoT, etc. However, it does not encompass comprehensive emerging technologies, such as biotechnology, for protecting national interests.

However, India has shown deep interest in building an advanced research and development cooperation framework related to economic security within the QUAD framework. Especially noteworthy are its specific efforts in establishing the Centre of Excellence cooperation framework for quantum research with Australia[192]. The attitude and measures shown by India in materializing its economic security policy through bilateral and multilateral cooperation will be of ongoing interest.

191 Emerging Technologies Division Promoting the Adoption of Cutting-edge Technologies to create Significant Economic and Societal Impact, https://www.meity.gov.in/emerging-technologies-division

192 Strengthening our technology partnership with India Statement 17 November 2021, https://www.foreignminister.gov.au/minister/marise-payne/media-release/strengthening-our-technology-partnership-india

2.3.3 Funding

A large portion of the financial support for science and technology innovation, based on an analysis of bibliographic data, is provided by federal government bodies and related agencies such as DST, SERB under its umbrella, DSIR, with private sector bearing about 30% of the research and development funding for the country as a whole[193]. A desire to perform research and development in the private sector is not widespread across the country. Additionally, as general funding bodies, there are the Council of Scientific & Industrial Research (CSIR) under DSIR, the Indian Council of Medical Research (ICMR) under the Ministry of Health and Family Welfare, the University Grants Commission (UGC) under the Ministry of Higher Education, the Indian Council of Agricultural Research (ICAR) under the Ministry of Agriculture and Farmers Welfare, the Board of Research in Nuclear Sciences (BRNS) under the Atomic Energy Commission[194], the Defence Research and Development Organisation (DRDO) under the Ministry of Defence, and the English DBT/Wellcome Trust India Alliance[195].

The government is also providing funds to encourage domestic manufacturing of pharmaceutical raw materials amongst businesses. In November 2020, the Indian government allocated a third stimulus package of 9 billion rupees (approximately 16 billion yen) for "Mission Covid Suraksha - the Indian COVID-19 Vaccine", accelerating vaccine development. In April 2021, DBT provided additional funding for the clinical trial of India's first mRNA-based COVID-19 vaccine HGCO19, developed by Gennova Biopharmaceuticals Ltd. based in Pune[196].

It is also funding various plans and programs to promote biotechnology research and development in India. Among these, the 2316 Biotechnology Parks promoted by DBT as ongoing projects (as of 2022), and the 60 bio-incubation centers promoted by BIRAC serve as crucial cores, with specific details introduced below.

The primary eligibility criteria for companies to apply for funding include: over 51% of the company's shares must be owned by Indian nationals, the company must have research facilities in India, must have obtained DSIR certification (refer to the DSIR section) and must be at a TRL level 7 with commercialization potential. If the funding is to be COVID-19 related, the research period must be within 12 months, and the intellectual property rights acquired must be owned by the company[197].

(1) National Biotechnology Park Scheme (DBT)

Under the Scheme, the central and state governments are working to stimulate biotechnology research in the country by establishing biotechnology parks, incubators, and pilot projects through public-private partnerships. The funding aims to provide financial support from the country to promote biotechnology product development, commercialization, and research innovation in the parks, offering scientists and SMEs opportunities for technology incubation, technology

193 From APRC-FY2021-RR-04 "Policy and R&D Trends for Science and Technology Cooperation with India".

194 Under the Department of Atomic Energy, there is the Tata Institute of Fundamental Research (TIFR) as a national research center. In the field of biology, there are the Department of Biological Sciences (Main Campus) in Mumbai, the National Centre for Biological Sciences in Bangalore, and the TIFR Centre for Interdisciplinary Sciences in Hyderabad.

195 A public charity funded by the DBT and the Wellcome Trust Foundation of the UK, established in 2008. India Alliance: https://www.indiaalliance.org/

196 DBT- S&T Interventions for COVID-19: https://dbtindia.gov.in/sites/default/files/DBT%27s%20Response%20to%20COVID-19_September%202021.pdf

197 DSIR R&D Funding Scheme, https://www.dsir.in/rdfunding.php (Accessed September 24, 2022)

demonstration, and research in pilot plants. The parks, centered around universities, are expected to act as effective bridges between science and industry, and also to financially contribute to the universities. All research institutes and other corporations established by state governments are eligible to apply. Existing parks seeking support can apply by clearly specifying the number of employees requiring advanced technology, the number of products, and the number of patent applications. Table 2-7 summarizes the main parks and their activities.

Financial support guidelines are calculated based on the size of the park and the number of participating companies, for example, in the case of existing facilities, this is either 50% of the lease or less than 75 rupees (about 133 yen) per foot, whichever is lower. For new facilities, financial support from the country is 300 million rupees (about 534 million yen) per park or 75% of the project cost (90% for parks in underdeveloped regions) (the remaining 25% is borne by partners participating in the park setup), covering construction costs, management costs, machinery costs, etc. The land is to be provided by the local government. Projects are overseen by a monitoring committee, and funds are provided based on phase evaluations. Other detailed criteria are applied in the selection of parks.

Table 2-7 Biotechnology Parks[198]

Location & Name	Details of Initiative
Biotech Park (Lucknow, Uttar Pradesh)	The first incubator, co-founded by DST, DBT, and the Government of Uttar Pradesh. The park hosts 18 common facilities and 27 measurement facilities, accumulates 36 startups, utilizes nearby research facilities such as CSIR and ICAR, focuses on the development of agricultural products, biofertilizers, biopesticides, and contributes to talent development. It is famous for developing disease-free banana varieties through tissue culture.
Biotechnology Incubation Centre (Hyderabad, Telangana)	Established with the cooperation of CSIR-Indian Institute of Chemical Technology (CSIR-IICT), DBT, and state government, owned by the Society for Biotechnology Incubation Centre (SBTIC). It is equipped with advanced instruments such as Fourier Transform Nuclear Magnetic Resonance (FT-NMR) equipment (500MHz) and LC-Q-TOF/MS/MS. This facility is characterized by conducting everything from process development to quality analysis and performance evaluation of pharmaceuticals[199].
Biotech Park (BTCIF) (Chennai, Tamil Nadu)	Established by the Tamil Nadu Industrial Development Corporation (TIDCO) with support from the state government and DBT, it is equipped with a series of analytical devices like MALDI TOF/TOF and chromatography equipment, as well as biotechnology research facilities like microbial culture devices from 5L to 100L[200].

198 Biotech Parks & Incubators, DBT: Https://dbtindia.gov.in/schemes-programmes/translational-industrial-development-programmes/biotech-parks-incubators (Accessed September 24, 2022)

199 The Advanced Analytical and Characterization Facility (AACR) is located in Hyderabad’s high-tech business district, Genome Valley, and features cutting-edge analytical equipment: http://sbtic.org/AACR.html

200 TIDCO Centre for Life Sciences briefing materials: https://ticelbiopark.com/ticel-new/uploads/BTCIF%20Brochure-2020.pdf

The Golden Jubilee Biotech Park For Women (Chennai, Tamil Nadu)	The park's association was established in 2001 with the vision of encouraging female entrepreneurs in the life sciences field, supported by the Government of Tamil Nadu and DBT. Since its establishment, it has nurtured 500 female entrepreneurs and engineers, with nearly 200 currently working there. It is supported by BIRAC and is equipped with general research facilities, functioning as an incubation center[201].
Biotech Park Technology Incubation Centre (GBPIC) (Guwahati, Assam)	Assam is a biodiversity-rich hotspot area. The center was authorized in 2009 and established near IIT Guwahati and Gauhati University. It houses eight modular labs and is equipped with shared measurement facilities for precision measurement. It aims to revitalize the state's economy through promoting employment and the development of products utilizing natural resources[202].
Biotechnology Park (Bangalore, Karnataka)	Authorized in 2005 with contributions from Karnataka Biotechnology and Information Technology Services (KBITS), the state government, and DBT, serving as an innovation center for biotechnology startups, fully equipped with various measurement devices, mammal and plant tissue culture facilities, animal houses, etc.[203].
Kribs Bionest (Kochi, Kerala)	Established within the Kerala Biotechnology Park. Previously known as KINFRA Biotech Park. Its facilities are managed by the Rajiv Gandhi Centre for Biotechnology (RGCB) and Kerala Startup Mission (KSUM). It is equipped with cell biology and genomics research facilities such as next-generation sequencers and cell sorters, in addition to in vivo imaging systems in animal houses and 100L culture tanks. It houses 28 startups (with an additional two companies participating virtually), with five companies having already graduated[204].

(2) Funding by BIRAC

BIRAC, a non-profit company established by DBT, primarily targets SMEs to bridge the gap in academic-industrial innovation research and promotes programs and platforms related to establishing and operating innovative, high-quality, and affordable product development through cutting-edge technology. Table 2-8 summarizes its main programs related to academic research.

201 Bio-NEST facility: https://www.biotechpark.co.in/bionest.htm

202 GBPIC Guwahati Biotech Park: https://gbp.assam.gov.in/portlet-innerpage/guwahati-biotech-park-incubation-centre

203 Bangalore Biotech Park: https://dbtindia.gov.in/bangalore-biotech-park-karnataka

204 RGCB BioNEST site: https://rgcb.res.in/BioNest/facilities.php

Table 2-8 Main BIRAC Programs

Programs	Content
Bio-NEST[205] (Incubation)	Supports startup establishment by academia through providing space for entrepreneurs, entrepreneur exchange, intellectual property management, etc., aiming to promote an innovation ecosystem. Has supported 63 universities and research institutions such as the University of Delhi and the University of Hyderabad, resulting in the creation of 200 products and 250 patent applications.
Promoting Academic Research Conversion to Enterprise (PACE)[206]	Provides support up to proof of concept (PoC) for solving national and societal challenges. (1) The Academic Innovation Research (AIR) category offers support of 5 million rupees (about 8.9 million yen) for 1.5 years. It excludes basic/exploratory research or proposals with low commercial value, requiring applicants to be the lead author of the paper forming the basis of the PoC or to have filed a patent. (2) The Contract Research Scheme (CRS) targets proposals above TRL-3, requiring academia to be the applicant, while also making an industrial partner mandatory. There is no set limit for the support duration and grant amount.
Biotechnology Ignition Grant Scheme (BIG)[207] (Idea to early stage)	BIRAC's flagship program. Supports startups and entrepreneurs from conception to proof stage with 5 million rupees (about 8.9 million yen) for 1.5 years. Held biannually in January and July, selected projects are managed through 8 national partner institutions like DBT-supported C-CAMP and DST-supported KIIT-Technology Business Incubator.
Biotechnology Industry Partnership Programme (BIPP)[208]	Supports high-risk public-private research in advanced fields. Conducts three calls for proposals annually targeting areas like a) drug delivery/pharmaceuticals, b) vaccines/clinical trials, c) biosimilars/stem cells, d) devices/diagnostic technologies, e) agriculture, f) industrial biotechnology, g) bioinformatics, following national priorities. Since its inception in 2008, it has supported 214 projects (as of the end of fiscal year 2020), resulting in 52 product creations.
AMRIT Grand Challenge (AMRIT GRAND CHALLENGE)[209] (New in 2022)	A new program announced in 2022 to support interdisciplinary, high-quality, high-risk R&D. Targets startups, industry, academia, and research institutions, planning to grant 1 to 1.5 billion rupees (about 1.78-2.67 billion yen) over 2-3 years. Focus areas include addressing national priorities and positioning India as a global leader in biotechnology, covering health, agricultural bio, climate change, synthetic biology, and sustainable biological resource management.

205 Bio-NEST site: https://birac.nic.in/bionest.php

206 PACE: https://birac.nic.in/desc_new.php?id=286

207 BIG site: https://birac.nic.in/big.php

208 BIPP site: https://birac.nic.in/desc_new.php?id=216

209 On August 22, 2022, Minister Shin of the Ministry of Science and Technology announced the establishment of the AMRIT GRAND CHALLENGE program to support fields such as health, agro-biotechnology, climate change, synthetic biology, and sustainable bioresource management, addressing national priorities and advancing India as a global leader in biotechnology. Reference video: https://www.indiascience.in/videos/amrit-grants-for-biotech-initiatives-e (Accessed December 25, 2022)

BIRAC's synthetic biology-related R&D efforts, as of 2020, are primarily targeting research fields within the Biotechnology Ignition Grant Scheme (BIG) as below[210].

- Pathway/genome engineering in microorganisms and algae for fine chemicals, specialty chemicals, polymers, bio-lubricants, and hydrocarbons.
- Improved enzyme systems.
- Development of synthetic genetic parts and circuits.

This funding targets individual or team applications, focusing on innovation research for companies, consortia, academia, and startups, and excludes basic research. The maximum support amount is 5 million rupees (about 8.9 million yen), with a maximum research period of 1.5 years. Supports domestic projects in synthetic biology, including construction of a BioBrick library using CRISPR-Cas9 by Saha Institute of Nuclear Physics, anthocyanin production by yeast at Central Food Technological Research Institute (CFTRI), and hyaluronic acid production by IIT Madras, with 11 projects selected[211].

According to the announcement[212] by the Minister of Science and Technology on August 22, 2022, DBT-BIRAC established the AMRIT GRAND CHALLENGE program to support interdisciplinary, high-quality, high-risk R&D in fields including synthetic biology by startups, industry, academia, and research institutions, preparing a grant of 1-1.5 billion rupees (about 1.78-2.67 billion yen) over 2-3 years. It is hoped it will accelerate R&D that fully utilizes the facilities and advanced research equipment installed in existing biotechnology parks, etc.

2.3.4 Main Research Institutions and University R&D Trends

Synthetic biology research in India mainly involves national biotechnology parks and the surrounding historic universities and research institutions listed in section 2.2.3 as main players, which are equipped with cutting-edge research infrastructure. In this section, major research institutions and universities, including those under the jurisdiction of the Department of Biotechnology (DBT), are shown in Figure 2-7. Additionally, institutions among the main players that are notably active are introduced below.

(1) Centre for Cellular and Molecular Platforms (C-CAMP)

The Centre for Cellular and Molecular Platforms (C-CAMP) is one of BIRAC's flagship centers, established in 2009. It is positioned as a national incubator for biostartups, located in Bangalore, Karnataka, which is often referred to as India's Silicon Valley and a center of innovation. C-CAMP houses infrastructure necessary for drug discovery support and biotechnology research, including high-resolution 3D X-ray microscopes, mass spectrometers, electron microscopes, and recombinant model organisms. It is also part of the Bangalore Life Science Cluster (BLiSC) along with NCBS, inStem, and Tata Institute for Genetics and Society (TIGS) and has produced a strong presence by funding over 330 startups. The most successful of these startups is Bugworks, founded in 2014, which develops novel

210 R&D Proposals 2020 in Synthetic Biology by BIRAC, India: Https://researchersjob.com/rd-proposals-2020/ (Accessed September 24, 2022)

211 List of Projects Adopted in Synthetic Biology by BIRAC-BIG: https://birac.nic.in/projects_supported.php?scheme=16&iscomplete=5 (Accessed September 24, 2022)

212 DST Press Release: https://pib.gov.in/PressReleasePage.aspx?PRID=1853621

antibiotics that can act on Gram-negative and Gram-positive drug-resistant bacteria (anti-microbial resistance, AMR). It is discovering first-in-class antibiotics through the ELUDE^{tm} platform. In 2017, it was the first in Asia to be selected for a grant by the global network CARB-X (Combating Antibiotic Resistant Bacteria Accelerator), led by Boston University, to accelerate the development of new antimicrobials[213]. It has expanded to Western countries, Japan, and Australia.

Another successful global company that has taken advantage of the global trend toward precision medicine is Strand Life Sciences, a bioinformatics-based company that takes advantage of India's status as an IT powerhouse.

C-CAMP is actively fostering partnerships for funding and collaboration with international institutions like Swissnex, the Indian government, domestic universities, and the industrial sector. In November 2022, Principal Scientific Adviser Ajay Kumar Sood (former professor at the Indian Institute of Science, IISc), announced the establishment of the Bangalore Science and Technology Cluster (BeST) in the area. This cluster is a collaborative effort involving the Indian Institute of Science (IISc) and C-CAMP, aiming to strengthen research and development in areas such as health, precision agriculture, urban transport, monsoons and climate change, quantum technology, and robotics.

(2) Jawaharlal Nehru University - Biofoundry India

The university that compiled the "Foresight Paper" mentioned in section 2.3.2, it is the sole Indian member of the Global Biofoundries Alliance (GBA). Operating as an open platform, it offers talent development and analytical support. Equipped with various advanced measurement and analysis instruments, including laser microscopes capable of live imaging and facilities for protein X-ray crystallography analysis. It is co-represented by Professor Binay Panda[214] of Jawaharlal Nehru University and Professor Pawan Kumar Dhar, who was previously mentioned. Professor Panda also serves as the Indian contact for the international project known as Genome Project-Write (GP-Write).

213 CARB-X https://carb-x.org/partners/global-accelerator-network/

214 Professor Panda earned his Ph.D. from Oxford University and has postdoctoral experience at the Scripps Research Institute in the US. He also has experience as a visiting researcher at the Technical University of Denmark (DTU) and the University of Tokyo Institute of Medical Science. In Nature India (2016), he raised issues regarding open access to papers and the use of clinical big data in India. https://www.nature.com/articles/nindia.2016.71

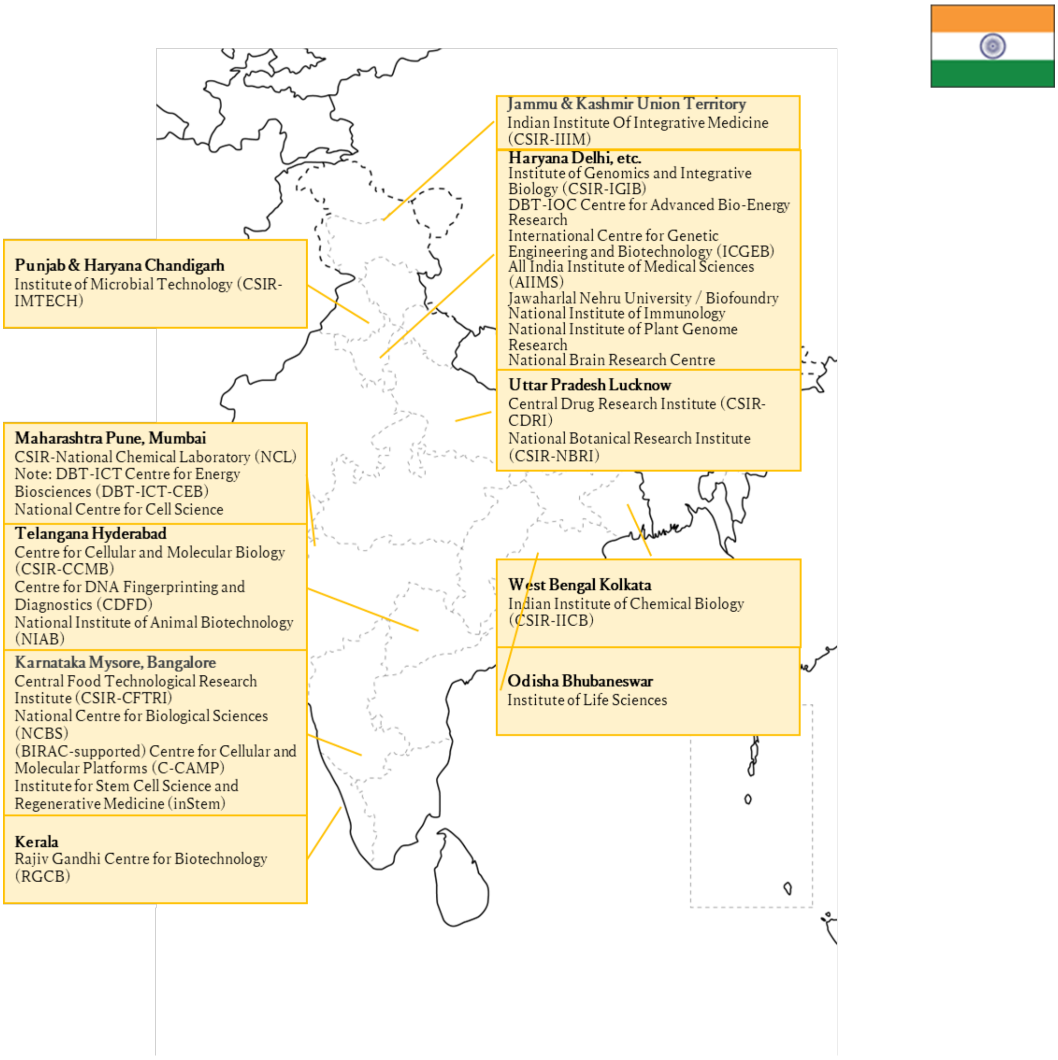


Figure 2-7 Major Research Institutions Related to Synthetic Biology in India

In addition to the two institutions mentioned above, the following autonomous research institutions are also present under DBT[215].

- National Institute of Immunology, New Delhi
- National Centre for Cell Science (on the campus of Pune University), Maharashtra
- National Brain Research Centre, Haryana
- Centre for DNA Fingerprinting and Diagnostics (CDFD), Hyderabad
- National Institute of Plant Genome Research, New Delhi
- Institute of Life Sciences, Bhubaneswar, Odisha
- Institute of Bioresources and Sustainable Development (IBSD), Imphal, Manipur
- Rajiv Gandhi Centre for Biotechnology (RGCB), Kerala

215 Autonomous research institutions under DBT: https://dbtindia.gov.in/about-us/organization-structure/autonomous-institution

- Institute for Stem Cell Science and Regenerative Medicine (inStem), Bangalore
- Translational Health Science and Technology Institute, NCR Biotech Science Cluster, Gurgaon
- National Institute of Animal Biotechnology (NIAB), Hyderabad

2.3.5 Trends in Major Industries

India’s primary biotechnology industries are categorized into biopharmaceuticals, bioindustrials, bioagriculture, bioIT, and the bioservices sector (manufacturing, research, and clinical trial outsourcing). The biotechnology sector’s skilled workforce is believed to exceed 1 million people. Segment contributions are as follows: vaccines 17.8%, bio IT/medical research 15%, COVID bioeconomy 7.8%, diagnostics/medical devices 25.6%, BT cotton[216] 14.4%, biofertilizers/biopesticides 1.4%, enzymes 3.7%, biofuels 3.6%, biologics/therapeutics 10.7%[217], with vaccines[218] and diagnostics/medical devices leading the way.

Particularly in the field of biopharmaceuticals, India plays a crucial role globally in vaccine manufacturing, significantly contributing to the supply of DPT, BCG vaccines, and biosimilars.[219] India operates 665 factories approved by the FDA, second only to the USA, with over 1,400 manufacturing facilities meeting WHO standards, and accounts for 44% of new drug applications worldwide[220]. According to SynBioBeta[221], a US-based company, India, which has a high prevalence of genetic disorders like beta-thalassemia and sickle cell anemia, is expected to produce developments in effective treatments using genome editing technologies.

The growth of the industry is attributed domestically to the government’s Make in India and Startup India policies, and internationally to the strong demand for Indian vaccines[222] and biopharmaceuticals. Additionally emphasized are the draft of the “National Policy on Research & Development & Innovation in Pharma-MedTech Sector”[223] announced at the end of 2021, the industrial nurturing measure known as PLI[224]and clinical trial rules[225], support for foreign

216 India is the world’s largest cotton producer, cultivating Bt cotton (genetically modified cotton with insecticide-resistant genes) introduced by Monsanto (at the time) in the 2000s.

217 “India’s Biotechnology Sector: How India is Reinventing the Future” , Ajjay Kumar Guputa, NIIR PROJECT CONSULTATION SERVICE, April 19, 2022:
https://www.linkedin.com/pulse/indias-biotechnology-sector-how-india-reinventing-future-gupta

218 India’s Serum Institute and America’s Novavax have partnered to produce COVID vaccines. The world’s first DNA vaccine was developed by Zydus Cadila, based in Ahmedabad.

219 The biosimilar market is growing at 22% annually and is expected to reach $25 billion by 2025.
https://www.investindia.gov.in/sector/biotechnology(Accessed September 22, 2022)

220 Biotechnology industry in India , https://www.ibef.org/industry/biotechnology-india

221 SynBioBeta, a media company based in California, USA (founded and CEO by John Cumbers), provides information related to synthetic biology and hosts events such as the Global Synthetic Biology Summit for scientists, engineers, inventors, entrepreneurs, and investors.
URL:
https://www.synbiobeta.com/read/jugaad-epitomized-a-deep-dive-into-indias-synthetic-biology-scene

222 India exports vaccines to over 150 countries (same as above).

223 “Draft policy to catalyse R&D and innovation in pharma-MedTech sector”
https://pharmaceuticals.gov.in/sites/default/files/Draft%20Policy.pdf (Accessed September 22, 2022)

224 PLI: An initiative started by the Government of India to not only encourage foreign companies to find workforce in the country and thereby generate employment, but also encourage domestic and local production to create micro jobs
https://cleartax.in/g/terms/pli-scheme (Accessed September 22, 2022)

225 The new drug/clinical trial regulations of 2019 are perceived to reduce costs, shorten approval times, and simplify procedures for the pharmaceutical market.

investment in the pharmaceutical/medical device industry, and India's epidemiologically unique background[226]. The strong support by BIRAC for strategic projects that advance ideas to commercialization amongst biotechnology-related technologies and products is also crucial.

The pharmaceutical industry, the largest segment of the biotechnology industry, accounted for 62% of the total (in 2020), with its size projected to reach 65 billion US dollars (about 8.255 trillion yen) by 2024, and further expected to reach 120 to 130 billion US dollars (about 16.51 trillion yen) by 2030[227]. The export value of pharmaceuticals is 23.04 billion US dollars (about 2.921 trillion yen), accounting for 5.92% of the global pharmaceutical demand[228], with formulations and biologics making up the majority (73.31%) of India's export value[229].

In the synthetic biology-related industries, India accounted for 8.9% of the Asia-Pacific synthetic biology market in 2020, not reaching Australia's 15.3%. This market is predicted to grow from 163 million US dollars (about 20.7 billion yen) in 2021 to 567 million US dollars (about 72 billion yen) by 2026, with an annual growth rate of 28.3% during the forecast period.

The following section will discuss two companies that dominate sales in India as pharmaceutical companies and two companies that have garnered attention for their R&D activities introduced in section 2.2.4(1).

(1) Sun Pharmaceutical Industries Limited[230]

Sun Pharma, founded in 1983, is the world's fourth-largest generic pharmaceutical manufacturer, boasting annual sales of 5.1 billion US dollars (about 627.3 billion yen). With over 40 manufacturing facilities, it produces high-quality, affordable medicines, earning the trust of medical professionals and supplying to over 100 countries worldwide. The company focused on technological differentiation through early investment in R&D, addressing complex product development through talent development and the establishment of pharmaceutical development strategy teams.

Its products range from generics to specialty pharmaceuticals targeting both chronic and acute diseases, sensitively responding to the demands of trading countries' regions. The importance of science in pharmaceutical development is central to the company; it has a research team comprising over 2700 researchers based in six research centers in India, Israel, and the USA. It holds over 1400 patents.

(2) Aurobindo Pharma Limited[231]

Aurobindo Pharma Limited began its operations in 1992 and was listed on the stock market in 1995, becoming the second-largest pharmaceutical company in the Indian market. Initially, the company specialized in semi-synthetic penicillin, later expanding its performance in areas such as psychiatry, cardiovascular, antiretrovirals, diabetes, the gastrointestines, and antibiotics. In 2020/21, it recorded sales of $3.3 billion, exporting to over 150 countries, with 90% of its revenue derived from exports.

226 The patient pool in India is expected to grow by more than 20% over the next decade due to population growth. Indian Biotechnology Industry Analysis https://www.ibef.org/industry/biotechnology-presentation (As above)

227 IBEF Posters on Indian economy and business https://www.ibef.org/mediaevents/posters(Accessed September 22, 2022)

228 Pharmaceutical export from India: https://www.ibef.org/industry/biotechnology-india

229 India Brand Equity Foundation "Indian Biotechnology Industry Analysis" 2021, https://www.ibef.org/industry/biotechnology-india (Accessed September 22, 2022)

230 https://sunpharma.com/

231 Excerpt from https://www.aurobindo.com/

It is India’s largest research facility, with five domestic research centers spanning a total area of 16,000 square meters. It also has three research and development centers in the USA. The company employs over 1,700 scientists and analysts. In particular, its research and development center in Hyderabad is equipped with the latest technology, houses an interdisciplinary research team of over 700 people across more than 13,000 square meters, fosters a creative environment, and supports its new drug development team with complex *in vitro* analysis and bioanalytical methods.

(3) Strand Life Sciences

Strand Life Sciences was the first company to spin off from the India Institute of Science in 2000. Focused on genomics-based research and diagnostics, the company aims to decipher genetic information contained within the genome to enhance global health.

Its powerful genomics solutions contribute to accelerating drug discovery research for pharmaceutical and biotechnology companies. Through access to genomics data along with clinical and phenotypic data, it enables insights at the genetic and molecular levels for complex diseases, promoting research in personalized medicine.

Its partnerships with Strand Life Sciences enable large-scale genomics research. The company collaborates with thousands of scholars and physicians, applying next-generation genomics to generate valuable insights in disease areas such as cancer, cardiovascular and metabolic diseases, eye, and neurological disorders.

It enables targeted treatments and preventive medicine for diseases through accurate diagnostics and genetic testing using next-generation sequencers. With the latest technology and its proprietary analysis and interpretation platform, it provides quick and reliable guidance on optimal treatment and prevention options. Strand Life Sciences is a testing facility accredited by CAP (College of American Pathologists) and NABL (National Accreditation Board for Testing and Calibration Laboratories), being the first in India to receive both prestigious certifications for NGS testing. It has an interdisciplinary team of over 220 pathologists, scientists, and engineers, with about 50% of scientists holding PhDs from leading research institutions worldwide, and engineers from top domestic universities providing computational capabilities for complex analyses. For nearly 20 years, it has developed robust and sophisticated bioinformatics solutions through GeneSpring, and Strand NGS, which are based on its proprietary platforms Ramanujan and Avadis. Strand Life Sciences operates the highest number of three CAP-accredited central labs among lab providers in India. Its tests cover a wide range from rapid point-of-care tests to the most specialized molecular level tests for cancer, genetics, infertility, maternal and child health, infectious diseases, and algorithm-based wellness.

(4) Bugworks[232]

Bugworks was established in 2014 and was incubated at C-CAMP. Its core team of scientists has over 200 years of drug discovery experience, partnering with several globally renowned partners to drive groundbreaking broad-spectrum activities. The company started as a small group of dedicated and skilled scientists aiming to tackle solutions before the global challenge and severity of global health issues worsen. It is currently headquartered in the USA, with subsidiaries in India and Australia. Over the years, the company has diversified its expertise in the areas of cancer biology and immunology, developing new classes of broad-spectrum antimicrobials and immunotherapies needed for critical care in infectious diseases and cancer.

232 Excerpt from https://bugworksresearch.com/

The most recent class of novel antibiotics was discovered in 1987, but antimicrobial resistance (AMR) remains a major contemporary challenge with devastating and long-term impacts. The company has been continuously engaged in the research and development of new antimicrobial therapies, ensuring both patients and society can benefit from effective AMR strategies. It is also working on evolving immunotherapy to new stages. The company's research program is focused on the discovery of affordable, differentiated small molecule therapeutics for high-density, hypoxic tumors. It emphasizes the extremely important role adenosine plays in creating an immunosuppressive and tumor-promoting environment. It believes a deep understanding of the medicinal chemistry and the tumor microenvironment can provide a kickstart to initiate and maintain a strong anti-cancer response by the immune system, and that this has the potential to make current immunotherapies more effective. In April 2021, it announced receiving funding from the US Defense Threat Reduction Agency (DTRA) to support the development of a novel broad-spectrum antibiotic, BWC0977, to counter the most critical bacterial biothreats[233].

2.4 United States (Comparative Reference Information)

2.4.1 Major Policies and Key Issues

Many of the technologies and tools that enabled the development of synthetic biology were developed in the United States. The United States continues to lead the field due to substantial and ongoing support for research and development in biotechnology, the presence of a high number and quality of startups, and a functioning innovation ecosystem through academia-industry-government collaboration. On January 20, 2021, President Biden, in a letter to Dr. Eric S. Lander, the Presidential Science Advisor and Director of the White House Office of Science and Technology Policy (OSTP) at a cabinet-level post, stated, "From artificial intelligence to synthetic biology, new technologies that can alter our lives are emerging at an ever more rapid pace."

He posed questions about how the US can remain a global leader in future technologies and industries essential for economic prosperity and national security, with a focus on competition with China[234].

Recent US presidential administrations have focused on promoting and regulating biotechnology and its foundational research and development from a national security and defense strategy perspective. However, significant policies related to biotechnology date back to the 1980s, the dawn of biotechnology, as shown in Table 2-9, including the development of PCR methods and genome sequencers.

233 Referenced https://kyodonewsprwire.jp/release/202104264129

234 The White House, "A Letter to Dr. Eric S. Lander, the President's Science Advisor and nominee as Director of the OSTP," January 15, 2021: https://www.whitehouse.gov/briefing-room/statements-releases/2021/01/20/a-letter-to-dr-eric-s-lander-the-presidents-science-advisor-and-nominee-as-direct

Table 2-9 Overview of Recent Biotechnology-Related Policies

Administration	Overview
Reagan Administration	· In 1986, the OSTP announced the "Coordinated Framework for the Regulation of Biotechnology," outlining a comprehensive federal regulatory policy to ensure the safety of biotechnology products.
Obama Administration	· Focused on updating the aforementioned framework and its accompanying guidance. Clarified the roles and responsibilities of federal agencies in biotechnology regulation. · The National Science and Technology Council (NSTC) published numerous reports during Obama's second term (2013-2017), focusing on various aspects of biotechnology, including biosecurity/biosafety and biosurveillance[235, 236].
Trump Administration	· Hosted the Bioeconomy Summit [237,238], conducting outreach to industry and focusing on updating the regulatory approval process for agricultural biotechnology products. · In September 2019, the OSTP issued a "Request for Information (RFI) on the Bioeconomy," soliciting community input on how the US government can support the promotion of the bioeconomy, highlighting needs such as sustained and long-term federal investment in research and development in the bio sector, including synthetic biology[239, 240]. · It identified biotechnology as one of the emerging technology areas emphasized alongside AI, quantum information science, 5G/advanced communications, and advanced manufacturing as "industries of the future,"[241] although no major policies related to the promotion of research and development were issued.

235 U.S. Environmental Protection Agency, "National Strategy for Modernizing the Regulatory System for Biotechnology Products," September 2016: https://www.epa.gov/sites/default/files/2016-12/documents/biotech_national_strategy_final.pdf

236 The White House, "The Homeland Biodefense Science and Technology Capability Review (2016)," December 2016: https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/NSTC/biodefense_st_report_final.pdf

237 The White House, "SUMMARY OF THE 2019 WHITE HOUSE SUMMIT ON AMERICA'S BIOECONOMY," October 7, 2019: https://trumpwhitehouse.archives.gov/wp-content/uploads/2019/10/Summary-of-White-House-Summit-on-Americas-Bioeconomy-October-2019.pdf

238 George B. Frisvold. (2021) "Understanding the U.S. Bioeconomy: A New Definition", *Sustainability*, 13, 1627

239 Office of Science and Technology Policy (OSTP), "Request for Information on the Bioeconomy," 9 2019: https://www.federalregister.gov/documents/2019/09/10/2019-19470/request-for-information-on-the-bioeconomy

240 As an example of RFI responses, the Biotechnology Innovation Organization (BIO), representing the biotechnology industry, seeks sustained federal funding for basic biotechnology research and strong public-private partnerships in biosciences. They also emphasize the necessity of robust STEM education policies to secure a domestic workforce capable of leveraging "increasing high-paying science jobs." Other respondents included the American Society for Microbiology (ASM), the American Society for Biochemistry and Molecular Biology (ASBMB), and university associations.

241 The White House, "ADVANCING AMERICA'S GLOBAL LEADERSHIP IN SCIENCE & TECHNOLOGY -TRUMP ADMINISTRATION HIGHLIGHTS: 2017-2020," October 2020. [Online]. Available: https://trumpwhitehouse.archives.gov/wp-content/uploads/2020/10/Trump-Administration-ST-Highlights-2017-2020.pdf

	· The Bureau of Industry and Security (BIS) of the US Department of Commerce listed biotechnology (nanobiology, synthetic biology, genetic engineering, neuro-engineering) as an example of the 14 emerging technologies subject to regulation under the Export Control Reform Act (ECRA) and its subordinate regulations, the Export Administration Regulations (EAR). In addition, in conjunction with its participation in the Australia Group, a multilateral export control regime focused on dual-use items related to biological and chemical weapons, the Bureau of Industry and Security (BIS) has added several items to the Export Control Classification Numbers (ECCN) used in the Commerce Control List (CCL) for the purpose of identifying dual-use items subject to export controls[242].
Biden Administration	· Identified biotechnology as a priority research and development area for federal agencies, focusing on the development of biomedical technologies to address COVID-19 and related threats. · From a national security and defense strategy perspective, the 2021 U.S.-China Economic and Security Review Commission annual report recommended measures such as the collection and protection of non-human genome data, considering China’s enhanced national support for emerging technologies, including synthetic biology.

2.4.2 Main Research Institutions and University R&D Trends

The US leads in almost all areas of life sciences and bioengineering related to the genome, including genome sequencing, genome editing, and genome synthesis. As a leading country, it has countless institutions contributing to research and development in biotechnology, including synthetic biology, across academia, industry, and government. Below, is a list of key federal agencies involved in basic to applied research and security-related activities.

Table 2-10 Main Federal Agencies Advancing Biotechnology Research, Including Synthetic Biology

Agency	Sub-division	Main Responsibilities and Activity Overview
US Department of Agriculture (USDA)	National Institute of Food and Agriculture (NIFA)	NIFA provides federal funding to academia and private companies for research and development in the biotechnology fields of animals, plants, microbes, and insects.
	Agricultural Research Service (ARS)	ARS, USDA’s principal research agency, conducts much of its research at the Animal Biosciences & Biotechnology Laboratory (ABBL).

242 For instance, in June 2020, considering the potential use of the MERS coronavirus as a biological weapon, it was added to ECCN 1C351-Human and Animal Pathogen and Toxins, along with the addition of culture chambers to the technical note of ECCN 2B352-Equipment Capable of Use in Handling Biological Materials. In October 2021, nucleic acid assembler/synthesizer software capable of designing and constructing functional genetic elements from digital sequence data was added (classified under ECCN 2D352-’Software’ for Nucleic Acid Assemblers/Synthesizers).

Department of Defense (DOD)	Defense Advanced Research Projects Agency (DARPA)	DARPA’s Biological Technologies Office (BTO) undertakes initiatives to enhance military benefits through biosciences, including areas such as biomanufacturing and synthetic biology.
	Army Research Laboratory (ARL)	The ARL collaborates with universities like the University of Texas, UCSB-Institute for Collaborative Biotechnologies (ICB), and companies like Lockheed Martin, aiming for operational improvements in the Army through the TRANSFORME (*Transformational Synbio for Military Environments*) program using synthetic biology for custom material manufacturing.
	Naval Research Laboratory (NRL)	NRL’s Center for Bio/Molecular Science and Engineering conducts various biotechnology research and development projects, including synthetic biology surfactants.
	Manufacturing USA	Two manufacturing institutes sponsored by DOD, BioFabUSA and BioIndustrial Manufacturing and Design Ecosystem (BioMADE), support DOD-related biotechnology research and development.
Department of Energy (DOE)	Office of Science’s (DOE SC) Biological and Environmental Research (BER) Program	The DOE SC’s BER program provides substantial funding for the development of novel bioimaging technologies for microbial interactions using quantum technology, as well as for research into synthetic biology approaches for plants and microbes. BER collaborates with national laboratories to advance genome science and bioenergy science, funding four Bioenergy Research Centers (BRCs)[243]. In February 2022, Dr. Pamela Ronald, Feedstocks Division Director at the Joint BioEnergy Institute (JBEI) and biologist in the Environmental Genomics and Systems Biology Division (EGSB), won the Wolf Prize in Agriculture for her research on rice disease resistance and environmental stress resilience.
	National Virtual Biotechnology Laboratory (NVBL)	NVBL is a consortium of DOE national laboratories conducting biotechnology research and development in response to COVID-19.

243 DOE Bioenergy Research Centers (BRC): (1) The Great Lakes Bioenergy Research Center (GLBRC), led by the University of Wisconsin-Madison and Michigan State University, focuses on biofuel and bioproduct manufacturing from lignocellulose, (2) The Center for Bioenergy Innovation (CBI), led by Oak Ridge National Laboratory, focuses on plant science and genome engineering research, bio-process improvements, and bio-product development from lignin residue, working towards realizing a bio-economy society, (3) The Joint BioEnergy Institute (JBEI), led by Lawrence Berkeley National Laboratory, conducts research on bioenergy crop improvement, biomass glycation process development, and microbial enhancement for industrial use, (4) The Center for Advanced Bioenergy and Bioproducts Innovation (CABBI), led by the University of Illinois Urbana-Champaign, focuses on improving feedstock and energy crops like miscanthus, sorghum, and sugarcane, and has many fields. Designated by DOE as a BRC in July 2017.

US Department of Health & Human Services (HHS) - National Institutes of Health (NIH)	National Institute of Biomedical Imaging and Bioengineering (NIBIB)	NIBIB researchers provide research and development grants in the biomedical field for external researchers to conduct studies in synthetic biology, among other areas, through the Synthetic Biology Consortium. Additionally, in 2021, they supported a conference at the Keystone Symposium[244] on the theme of Synthetic Biology: At the Crossroads of Genetic Engineering and Human Therapeutics.
	National Human Genome Research Institute (NHGRI)	NHGRI leads NIH's genomic research, including novel nucleic acid synthesis technology development and follow-up studies of the Human Genome Project. In the Analysis, Visualization, and Informatics Lab-space (AnVIL) program[245], they operate a cloud-based genomic data sharing and analysis platform developed in collaboration with numerous research institutions and universities, including the Broad Institute and UC Santa Cruz.
National Science Foundation (NSF)	Biosciences Office (BIO)	BIO is the primary office providing funding for biological research and development projects, supporting various synthetic biology projects.

The following table details notable research and development programs that it supports based on its long-term strategies.

(1) DARPA Biological Technologies Office (BTO)

DARPA-BTO leads DARPA's efforts to leverage biosciences for American military interests. Recent topics under the BTO's "Syn-Bio" tag are covered below[246].

・B-SURE (Biomanufacturing: Survival, Utility, and Reliability beyond Earth)：

The Biomanufacturing: Survival, Utility, and Reliability Beyond Earth (BSURE) program is a program that collaborates with partners to explore the possibilities of biomanufacturing activities in space. The 2021 call for applications (HR001122S0010) outlines projects on the use of microbes for alternative materials in space, optimization of microbial growth under varying gravity, and mitigating the specific effects of galactic cosmic radiation on microbial growth and bioproduction.

・Bio-INC (Bio-Inorganic Nanoparticle Control):

The "Bio-Inorganic Nanoparticle Control (Bio-INC)" program involves research using microbes and biomolecules to synthesize tunable rare earth element (REE)-containing optical and magnetic inorganic nanoparticles (HR001121S0025, under the biotechnology category).

244 Keystone Symposia: A symposium for molecular and cell biology researchers, held annually in North America. Prominent researchers in each field plan the program, and researchers conducting the most current research are invited.

245 NHGRI , "Analysis Visualization and Informatics Lab-space,": https://anvilproject.org/ (Accessed February 2022)

246 DARPA, "Biological Technologies Office (BTO),": https://www.darpa.mil/about-us/offices/bto#OfficeProgramsList (Accessed February 2022)

・Living Foundries:

In December 2021, a decade after its launch in 2010, the Living Foundries program, which aims to program basic biological metabolic processes to produce precursors for over 1,000 molecules and materials across a wide range of defense-related applications, including industrial chemicals, fuels, coatings, and adhesives, announced that it had successfully manufactured over 1,630 molecules. Additionally, it announced it had successfully transferred these synthetic biomanufacturing technologies to five research laboratories of the Army, Navy, and Air Force[247]. Among the approximately 1630 molecules are compounds with interesting molecular properties for advanced polymer development, and potential uses include durable adhesives for vehicle structural purposes such as armored vehicles, and high-performance composite materials for aircraft and missile applications. The following are some development examples in this program.

- A team led by Dr. Ben Harvey at the Naval Air Warfare Center Weapons Division (NAWCWD), in collaboration with Amyris and Zymergen, developed tools and technologies for manufacturing high-performance chemicals and materials useful for various military applications. NAWCWD succeeded in converting precursor molecules into high-energy-density fuels, energy materials, heat-resistant polymers, and high-performance composite materials. These technologies are planned for further development through the Naval Research Laboratory (ONR) Bioengineering and Biomanufacturing Program, ONR Advanced Energy Manufacturing Pipeline, Wright Brothers Institute/Air Force Research Laboratory (AFRL) Synthetic Biology Challenge, and Bioindustrial Manufacturing and Design Ecosystem (BioMADE).
- Teams led by Dr. Greg Peterson, Dr. Jared DeCoste, and Dr. Vipin Rastogi at the Army's Combat Capabilities Development Command Chemical Biological Center (DEVCOM CBC) are developing filters, fabrics, and decontamination wipes to counter chemical and biological warfare agents using biological template materials provided by MIT. This technology is slated for further testing and development at DEVCOM CBC as part of the Defense Threat Reduction Agency's multifunctional materials program.

(2) Army Research Laboratory (ARL)

As the Army's leading research institution, ARL conducts the TRANSFORME (Transformational Synbio for Military Environments) program in collaboration with numerous universities (Texas A&M University, MIT, Tufts University, etc.) and companies (Lockheed Martin, Ginkgo Bioworks, etc.) as one of its foundational programs. Recent achievements include the development of a method for synthesizing fully symmetrical oligomers[248] using the Supercharged Protein Assembly (SuPrA) technique by the University of Texas at Austin, and the development of efficient and inducible DNA introduction tools[249] into bacteria in non-culturable environments by a team led by Professor Christopher Voigt of MIT, among others.

(3) Manufacturing USA BioFabUSA

Established in 2016. Operated by the Advanced Regenerative Manufacturing Institute (ARMI) in New Hampshire.

247 DARPA, "OUTREACH@darpa.mil," 8 12 2021: https://www.darpa.mil/news-events/2021-12-08

248 AJ Simon et al. (2019) "Supercharging enables organized assembly of synthetic biomolecules," *Nature Chemistry*

249 JAN Brophy et al. (2018) "Engineered integrative and conjugative elements for efficient and inducible DNA transfer to undomesticated bacteria," *Nature Microbiology*

With approximately $300 million in funding from the federal government and private sources, it integrates cell and tissue culture with biofabrication, automation, robotics, and advanced analytical technologies to create disruptive R&D tools and manufacturing processes.

Key projects include:

- Supporting the automated production of β cells for diabetes treatment. Received $2 million in funding from the Juvenile Diabetes Research Foundation.
- Through an automated manufacturing project for bones, ligaments, and muscles, in collaboration with STEL Technologies, it developed an automated process for tissue manufacturing (Tissue Foundry).

(4) DOE Advanced Research Projects Agency-Energy (ARPA-E) ARPA-E）

ARPA-E, modeled after the Department of Defense’s DARPA, is a high-risk, high-reward funding program in the energy sector. Recent synthetic biology-related projects include the Energy and Carbon Optimized Synthesis for the Bioeconomy (ECOSynBio) program[250]. It aims to facilitate the use of advanced synthetic biology tools for new biomass conversion platforms and system designs, focusing on (1) carbon-optimized fermentation strains that reduce CO2 emissions, (2) artificial organisms that mix different energy and carbon sources to curb CO2 production, (3) biomass-derived sugar and carbon dioxide gas fermentation technologies, (4) cell-free carbon-optimized biocatalysts for biomass conversion and CO2 utilization, and (5) other technologies, with 17 projects led primarily by companies and universities starting from 2021.

(5) Manufacturing USA BioMADE

The newest institution within the Manufacturing USA network. On October 20, 2020, the DOD announced it entered into a $87 million, 7-year contract with BioMADE[251]. It collaborates with 31 companies, 57 universities, and 6 non-profit organizations to accelerate research and development. BioMADE is led by members from the non-profit Engineering Biology Research Consortium[252] (EBRC) and is hosted by the University of Minnesota. Over the next seven years, BioMADE intends to develop industry standards, tools, and measurement technologies, cultivate a resilient bioindustrial manufacturing ecosystem, and nurture core companies within the supply chain crucial for propelling the bioeconomy in the United States. It will also place a strong emphasis on addressing societal challenges such as biosafety and ELSI.

As of February 2022, it had launched 10 innovation projects[253], including the development of a pilot-scale prototype manufacturing device for *in situ* removal of toxins (and their microbial sources) (Amyris) and large-scale fermentation production of succinic acid at pH 3.0 or lower (University of Illinois Urbana-Champaign), and plans to continue soliciting project proposals as needed. In the future, it aims for the industrial-level production of new bio-products

250 DOE-APRA-E, “ECOSynBio,”: https://arpa-e.energy.gov/technologies/programs/ecosynbio

251 DOD, “IMMEDIATE RELEASE DOD Approves $87 Million for Newest Bioindustrial Manufacturing Innovation Institute,” 20 10 2020.: https://www.defense.gov/News/Releases/Release/Article/2388087/dod-approves-87-million-for-newest-bioindustrial-manufacturing-innovation-insti/

252 EBRC: Members of the SynBERC (Synthetic Biology Research Center) program, supported by NSF for ten years, established to evolve and grow a broader synthetic biology community, including industry and international members. They are creating policy recommendations, research ethics ELSI (security), and education, along with a technology roadmap for priority areas of basic research over the next 20 years in microbiome and material science.

253 BioMADE, “Technology & Innovation Projects,”: https://www.biomade.org/projects (Accessed February 2022)

such as chemicals, solvents, detergents, plastics, fabrics, agricultural materials, and food additives.

A list of major universities with research centers related to synthetic biology, serving as key players from basic to applied research can be found in Table 2-11. Additionally, notable research centers specializing in biotechnology centered around the West Coast (which hosts many synthetic biology-related companies) include Stanford University (Bio-X), the University of California’s Center for Complex Biological Systems (CCBS), the University of Pennsylvania (Center for Cell and Developmental Biology, Center for Engineering Mechanobiology, Institute for Biomedical informatics, Nano/Bio Interface Center), the University of Wisconsin-Madison (Biotechnology Center), and Purdue University (Laboratory of Renewable Resources Engineering (LORRE), Biotechnology Innovation and Regulatory Science Center (BIRSC)).

According to the 2022 Technology Trends Report[254] by the New York City-based consulting firm Future Today Institute (CEO Amy Webb), notable universities and researchers emerging in synthetic biology[255], from perspectives of equipment development, CRISPR technology, and applications in medicine and food, include the Broad Institute, Dr. Drew Endy of Stanford University[256], and Professor Jay Keasling’s lab at DOE Lawrence Berkeley National Laboratory (also affiliated with the University of California, Berkeley).

Table 2-11 Main Universities Advancing Biotechnology Research, Including Synthetic Biology

Universities	Center Name	Overview
Johns Hopkins University (JHU)	Institute for NanoBioTechnology	Engineering approaches for cancer treatment, stem cell research, early diagnostic tools, and nano-scale process engineering.
	Institute for Basic Biomedical Sciences	Has a Center for Cell Dynamics studying cell and molecular dynamics using biosensors, an Epigenetics Center developing tools for exploring epigenetic factors in normal development and disease, and a Center for Metabolism & Obesity Research.
Northwestern University	Center for Synthetic Biology	Conducts synthetic biology research under four themes: cell-free systems, mammalian systems, technology platforms (such as high-throughput technologies), and ethical and social impact. Advisory members include Nobel laureate Professor Frances Arnold, who developed directed evolution methods, and Professor James J. Collins from MIT.

254 The Future Today Institute. (2022) “Synthetic Biology, AgTech & Biotech”: https://futuretodayinstitute.com/mu_uploads/2022/03/FTI_Tech_Trends_2022_Book12.pdf

255 Outside of academia and researchers, names such as ERS Genomics, CRISPR Therapeutics, Caribou Biosciences, Editas Medicine, Bayer, Ginkgo Bioworks, Twist Bioscience, Benchling, GenScript, BGI Group, Built with Biology (formerly SynBioBeta), J.C. Venter Institute (JCVI), Synthace, Codexis, Zymergen, Amyris, Viridos, and Sherlock Biosciences, mainly from the West, are mentioned as unicorns and major companies.

256 Chairperson of the Biobricks Foundation and co-founder of iGEM. The Biobricks Foundation, established by researchers including Dr. Tom Night, who moved from MIT to GinkgoBioworks, and Dr. Drew Endy, aims to standardize and standardize genetic information as “parts” in a library for free use.

	Simpson Querrey Institute for BioNanotechnology	Led by Professor Samuel I. Stupp, renowned for his research in self-assembling materials and supramolecular chemistry, the center focuses on regenerative medicine, targeted nanotherapeutics, biomimetic materials, and electrically active biomaterials. It is equipped with peptide synthesis devices.
Harvard University	Wyss Institute for Biologically Inspired Engineering	Aims to develop technologies for health, energy, architecture, robotics, and manufacturing based on biological design principles. Members of the institute who developed a strong hydrogel adhesion technology and soft robotic glove technology received the Harvard President's Innovation Challenge in 2022. An application-oriented institute, it is developing sensors with biofunctional chips and micro-sized robots produced using 3D printing technology. Its members include Professor George Church, mentioned in the section on China.
	Harvard Chan Microbiome in Public Health Center (HCMPH)	Conducts basic research in epidemiology, nutrition, cancer biology, immunology, etc., to deepen understanding of the microbiome and link it to the treatment of lifestyle-related diseases.
Massachusetts Institute of Technology (MIT)	Broad Institute	Features prominent figures performing cutting edge-research in synthetic biology, including Professor Eric Lander, former director of OSTP; Professor Christopher Voigt, who devised a programming language for bacteria; Professor Feng Zhang, known for applying CRISPR-Cas9 to mammals; and Professor David Liu, who is aiming to develop treatment methods for progeria through single-base modification.
	Whitehead Institute	Conducts basic research on cancer, cell mechanics, cell development and regeneration, genetics and genomics, infectious diseases, metabolism, neurodevelopment, plant biology, and the structure and function of proteins.
	Lincoln Laboratory	Located within Hanscom Air Force Base, Lincoln Laboratory is funded by MIT and the DOD to develop a wide range of advanced technologies addressing national security needs. The Biotechnology and Human Systems Division conducts research and development aimed at enhancing the health and performance of military personnel and dependents through enhanced disaster response capabilities, climate change adaptations, improved defense against biological and chemical threats, and the construction of artificial gut devices (enterobacterial flora research).
University of Illinois Urbana-Champaign	Roy J. Carver Biotechnology Center	A core research analysis facility supporting six categories of research: genomics, proteomics, metabolomics, bioinformatics, flow cytometry, and translational medicine.
	Center for Computational Biotechnology and Genomic Medicine (CCBGM)	An NSF-supported center promoting medical research using data analysis, artificial intelligence, machine learning, and high-performance computing. Works in collaboration with companies such as IBM and Infosys, along with Sandia National Laboratories.

Note: CABBI, a DOE-supported facility mentioned above, is excluded from this table.

3 Analysis of Scientific Papers and Patents

This chapter provides an overview of the research and development trends in synthetic biology in India, Australia, and, for reference, Japan, China, and the United States. This overview is based on common understandings that lead to the analyses in each chapter, drawing from information in academic journals and published patent data. Emerging biotechnology fields and synthetic biology-related keywords were extracted based on various papers, and a method to gain an overview of paper and patent information using natural language processing text analysis techniques was adopted.

For details, a separate report “Data landscape of emerging biotechnology articles and patents in major Asia and the Pacific regions (APRC-FY2021-RR-05 (reference material)),” was referred to, and the summary is provided below.

3.1 Population of Papers and Patents

Synthetic biology is an interdisciplinary field. With the intention of comprehensively collecting data, this analysis supplements the field’s trends since 2000 through bibliometric studies of prior articles, including those summarizing the trends of synthetic biology in the Asian region based on keywords mentioned in the articles, as well as panoramic view reports[257] from the JST Center for Research and Development Strategy (CRDS). A wide range of search keywords and formulas were set, targeting not only the technology but also the products utilizing the technology. This approach initially frames it as an “emerging biotechnology field” and subsequently focuses specifically on synthetic biology to compile the findings.

Clarivate’s academic literature database Web of Science was used to collect data on papers. For data on patents, LexisNexis’s TotalPatentOne (the world’s largest patent database) was used. The final population was collected without specifying countries, regions, or languages to assess the global picture.

[257] Ning Mao et al. (2021) “Future trends in synthetic biology in Asia”, *Advanced Genetics,* https://doi.org/10.1002/ggn2.10038
P. Shapira, S. Kwon , J. Youtie. (2017) “Tracking the emergence of synthetic biology,” *Scientometrics,* 1439-1469
JST/CRDS Panoramic View of the Life Science and Clinical Research Field (2021)

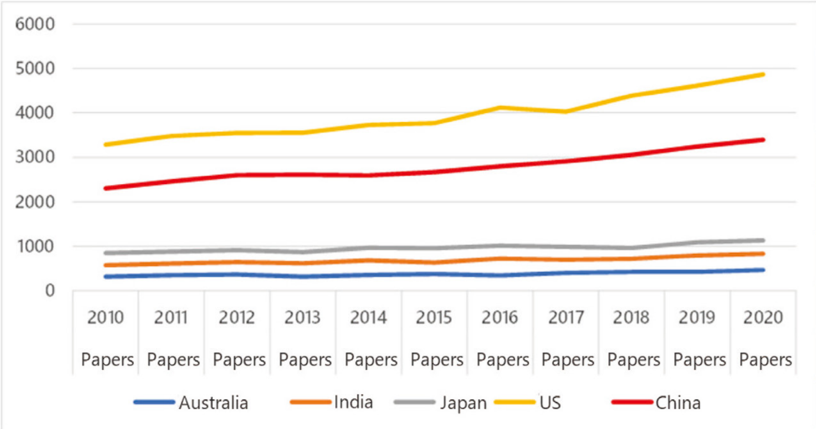
Table 3-1 Target Scope for Emerging Biotechnology Field Search

<table>
<tr><th>Item</th><th colspan="2">Papers</th><th colspan="2">Patents</th></tr>
<tr><td>Database Used</td><td colspan="2">Clarivate’s Web of Science</td><td colspan="2">LexisNexis’s TotalPatentOne</td></tr>
<tr><td>Type</td><td colspan="2">Article OR Proceedings</td><td colspan="2">Publication</td></tr>
<tr><td>Year Extracted</td><td colspan="4">2010-2020</td></tr>
<tr><td>Examples of Search Formulas & Keywords</td><td colspan="4">As per “Analysis of Paper and Patent Trends in the Emerging Biotechnology Field in Major Asia-Pacific Countries (APRC-FY2021-RR-05 (reference material)).” For reference, an example of a paper search formula is excerpted below. The patent analysis is synonymous with the above.
<table>
<tr><th>検索式No.</th><th>検索式</th></tr>
<tr><td>1</td><td>TS=(("RNA" OR "mRNA" OR "tRNA" OR "tmRNA" OR "snRNA" OR "sirna" OR "rRNA" OR "ncRNA" OR "RNAi" OR "dsRNA" OR "protein*" OR "chromosome*" OR "gene* circuit*" OR "gene* network*" OR "*nucleotide*" OR "nucleic acid*" OR "DNA" OR "genome" OR "promoter*" OR "terminator*" OR "bio*brick*" OR "Bioprospecting" OR "broad-host range plasmids" OR "Cell-free system*" OR "Codon optimization" OR "CRISPR*" OR "*Cas9" OR "Directed evolution" OR "DNA assembly" OR "DNA data storage" OR "biomolecular engineering" OR "Antibody engineering" OR "engineering biolog*" OR "metabolic engineering" OR "microbiome engineering" OR "protein engineering" OR "Receptor engineering" OR "RNA engineering" OR "Genome engineering" OR "protein engineering" OR "gene drive" OR "chromosome" OR "mammalian gene*" OR "mammalian*cell*" OR "mammalian-cell*" OR "organelle*" OR "yeast") Near/10 (synthe* OR Biosynthe* OR cloning))</td></tr>
<tr><td>2</td><td>TS=(("Modelling" OR "machine learning") NEAR/10 ("bio*" OR "DNA" OR "RNA" OR "metabolic" OR "genome" OR "chromosome" OR "RNA" OR "protein"))</td></tr>
<tr><td>3</td><td>TS=("artificial cell*" OR "synthe* cell*" OR "xenovirology" OR "xenobiology" OR "synthetic gene*" OR "synthetic biolog*" OR "synbio*" OR "biosynthetic gene*" OR "biosynthe* cell*")</td></tr>
<tr><td>4</td><td>TS=((("gen*" AND "edit*") AND （"synthe*" OR "Biosynthe*" OR cloning)))</td></tr>
<tr><td>5</td><td>SO=("ACS SYNTHETIC BIOLOGY" OR "SYNTHETIC BIOLOGY" OR "SYNTHETIC AND SYSTEMS BIOTECHNOLOGY" OR "ARTIFICIAL CELLS NANOMEDICINE AND BIOTECHNOLOGY" OR "Biofabrication" OR "Bio-Design and Manufacturing")</td></tr>
<tr><td>6</td><td>PY = (2010-2020) AND (DT= (Article) OR DT=(Proceedings Paper))</td></tr>
<tr><td>対象</td><td>(#1 OR #2 OR #3 OR #4 OR 5) AND #6</td></tr>
</table></td></tr>
<tr><td>Primary Population</td><td colspan="2">153,862</td><td colspan="2">71,442</td></tr>
<tr><td>Final Population (After Noise Removal)</td><td colspan="2">146,929</td><td colspan="2">57,603</td></tr>
<tr><td>Number of Items by Country in the Final Population (Percentage of Total Population)</td><td>Australia
India
Japan
United States
China</td><td>4157(2.8%)
7545(5.1%)
10632(7.2%)
43374(29.5%)
30632(20.8%)</td><td>Australia
India
Japan
United States
China</td><td>206(0.4%)
274(0.5%)
2760(4.8%)
14968(26.0%)
31500(54.7%)</td></tr>
</table>

The results of the search are shown in Figures 3-1 and 3-2 for the number of papers published and patent applications by each country, respectively. Papers are classified by the country of the author’s affiliated institution, and patents are classified by the country claiming priority.

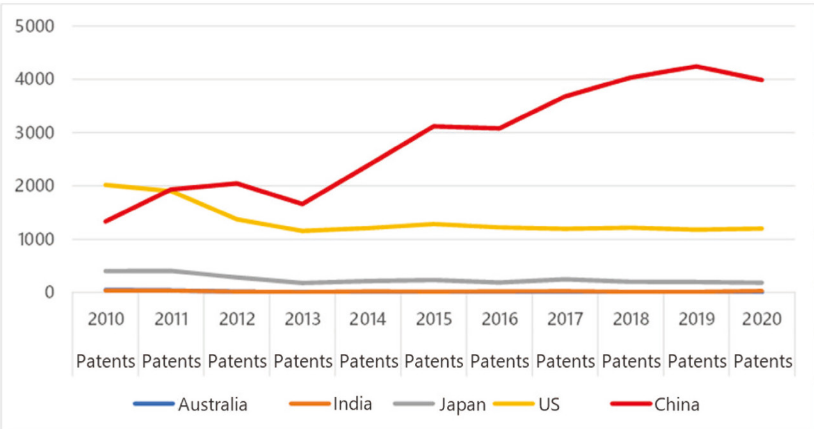
Regarding the number of papers, while Australia and India do not reach the levels of the United States, China, and Japan, they have been consistently publishing in recent years. The recent ratio of the number of papers [from 2018 to 2020 / total number over the entire period] is 30-32% for each country, showing no significant differences between countries, indicating a similar trend. Moreover, in terms of the total number of papers worldwide, the United States is followed by China, with Japan ranking fourth after Germany. India ranks sixth after the United Kingdom, and Australia is twelfth, following South Korea and Spain, in the number of published papers.

On the other hand, the number of patent applications from Australia and India is overwhelmingly lower compared to the three countries. Also, the recent ratio for Australia is lower, indicating that it is significantly behind other countries in terms of patents. Furthermore, the recent ratio for China is higher compared to other countries, clearly showing a proactive stance towards patent applications in the emerging biotechnology field, similar to other technology fields.



Country	Total (2010-2020)	Recent Ratio (2018-2020 vs 2010-2020)
Australia	4157	32%
India	7545	31%
Japan	10632	30%
US	43374	32%
China	30632	32%

Figure 3-1 Annual trend and recent ratio of published papers in the five countries



Country	Total (2010-2020)	Recent Ratio (2018-2020 vs 2010-2020)
Australia	206	16%
India	274	24%
Japan	2760	21%
US	14968	24%
China	31500	39%

Figure 3-2 Annual trend and recent ratio of published patents in the five countries

3.2 Global Research and Technology Areas Identified by Paper Analysis

3.2.1 Emerging Biotechnology Field

The final population of papers in the emerging biotechnology field was evaluated for similarity using topic modeling[258] and mapped onto a two-dimensional plane[259] through manifold learning[260]. As a global structure, Table 3-2 illustrates that based on characteristic words, names, summaries, and abstracts, the research was broadly divided into nine research and technology categories (excluding others): Informatics, Pathology, Infectious Diseases, Cell-Related, Protein Engineering, Biosensors, Metabolic Networks, Gene Function Analysis, and Gene Editing. Based on similarity, 74 individual areas (clusters) were identified.

Table 3-2 Nine Research and Technology Categories and 74 Individual Areas

Research and Technology Category	Individual Areas (Clusters)
Informatics	Machine learning, evaluation models, systematic studies, signal detection & processing
Pathology	Muscle formation & function, bone formation, lifestyle diseases, immune abnormalities & inflammation, neurological diseases & cognitive functions, tumors, heart-related diseases, miRNA and diseases, genetic factors, target proteins, interferons, germ cells
Infectious Diseases	HIV, HCV, dengue fever, influenza and other viruses, virus replication, tuberculosis, immune response
Cell-Related	Stem cell preparation, cell culture & preparation methods, cell culture related materials
Protein Engineering	Fusion proteins, recombinant protein expression, cell-free protein synthesis, fluorescent probes, receptor ligand binding, domain structure, translation initiation factors, ribosome biosynthesis, functional peptides (antimicrobial, etc.), antigen peptides, vaccines
Biosensors	DNA detection & construction, DNA methylation & demethylation, metal ion adsorption, nanoparticles
Metabolic Networks	Culture environment, biosynthetic pathways & control, E. coli & Bacillus subtilis, enzyme activity optimization, terpene biosynthesis, secondary metabolism biosynthetic genes

258 Topic Model (LDA: Latent Dirichlet Allocation) is a type of probabilistic model that estimates the “probability of word occurrence” in documents, evaluating documents with similar words as similar using basic natural language processing techniques.

259 The absolute position of the plot has no meaning; only the relative positions of each are important.

260 Manifold learning is a method of extracting lower-dimensional data from higher-dimensional data, for example, reducing 3D data to 2D to reduce computational complexity.

Gene Function Analysis	Gene expression regulation, sequencing, plasmids & vectors, aptamers, molecular markers, methanol-utilizing yeast, plant-related genes, insect-related genes
Genome Editing & Gene Modification	Primers, nucleic acid preparation, chromosome preparation, CRISPR-Cas
Other	Others include information processing of images & sounds, feed & environmental impact, microbial diversity & environmental purification, mitochondrial function, DNA damage & repair, DNA replication, parasites, gene interactions & complexes, tRNA synthetase, natural extracts, compound synthesis & applications, probiotics & prebiotics, fatty acids, antibodies, traditional Chinese medicine

Figure 3-3 is a map showing the temporal changes in paper information from 2010 to 2020. Each point in the map represents paper information, and clusters (individual areas) were identified by red dotted lines based on similarity. The map visualizes the density of paper data, with areas of high density (where data accumulates) indicated by colors from red, yellow, green, blue, to black (no data).

From 2010 to 2013, papers were distributed across a wide range of fields, with strong concentrations in individual areas such as “microbial diversity & environmental purification,” “muscle formation & function,” “fusion proteins,” “enzyme activity optimization,” “gene interactions & complexes,” and “tRNA synthetase.” During the period from 2014 to 2017, strong concentrations were observed in new individual areas like “evaluation models,” “signal detection & processing,” “CRISPR-Cas,” indicating a period of increased interest in the “Informatics” category and CRISPR-Cas, a breakthrough technology in genome editing. From 2018 to 2020, strong concentrations were seen in “machine learning” and “secondary metabolism biosynthetic genes.” In “machine learning,” papers related to synthetic biology were seen, utilizing omics data for machine learning & predictive models, and in “secondary metabolism biosynthetic genes,” papers related to metabolic engineering and the exploration of useful secondary metabolites were observed.

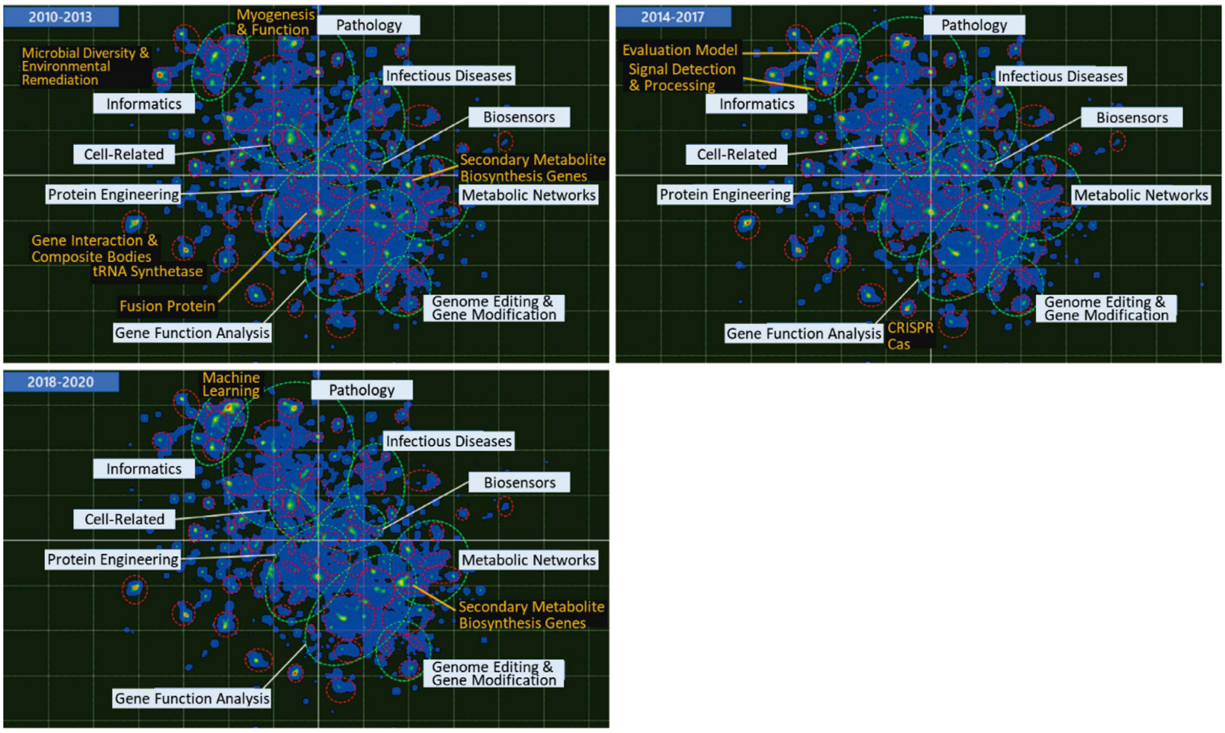


Figure 3-3 Temporal changes in the research & technology map of papers

To understand the temporal changes in paper information in more detail, the number of papers from 2010 to 2020 and the recent ratio (the ratio of the number of papers published from 2018 to 2020 to the number of papers published from 2010 to 2020, hereinafter referred to as the recent ratio) for each research & technology category are shown in Figure 3-4. The category with the highest number of papers is “Pathology,” followed by “Gene Function Analysis” and “Protein Engineering.” These categories have a wide distribution on the research & technology map, suggesting that they include a variety of themes with different contents.

On the other hand, the category with the highest recent ratio is “Informatics,” which is supported by “Machine Learning.” This is followed by “Metabolic Networks” and “Genome Editing & Gene Modification,” driven by technological advances in CRISPR-Cas, indicating an increase in activity in these areas. Excluding “Informatics,” there is no significant difference in the recent ratio between categories, but the categories with a high number of papers mentioned above generally have a relatively low recent ratio. The three categories with a high recent ratio, although having a small number of papers, may see an increase in the future.

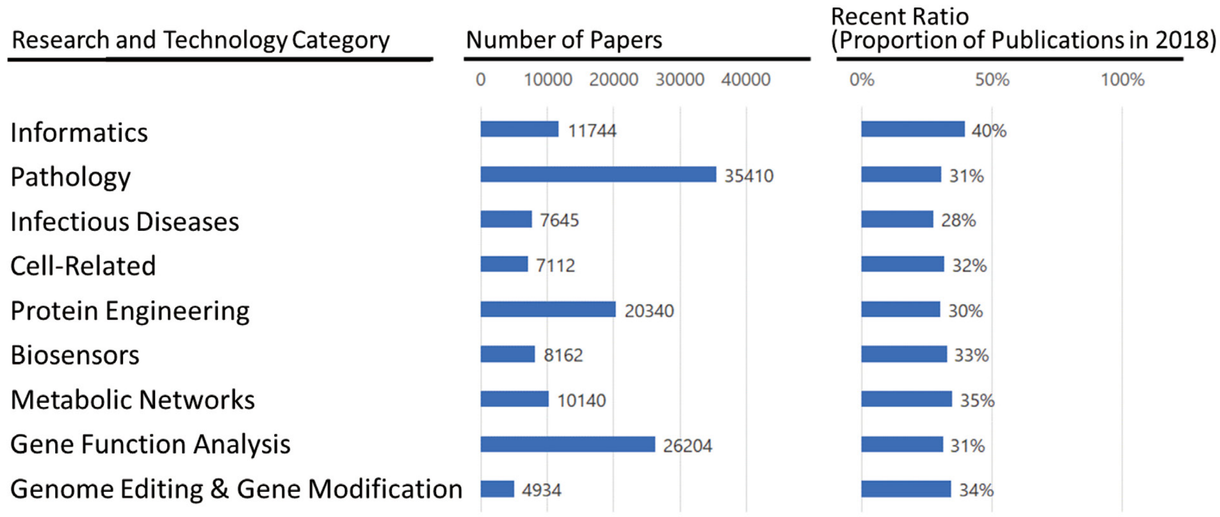


Figure 3-4 Number and recent ratio of papers by each research & technology category

3.2.2 Synthetic Biology Field

Based on the data and analysis of the previous section, the temporal changes in papers containing keywords specific to synthetic biology were analyzed. Figure 3-5 shows the transition of papers containing keywords related to synthetic biology published from 2010 to 2013, from 2014 to 2017, and from 2018 to 2020.

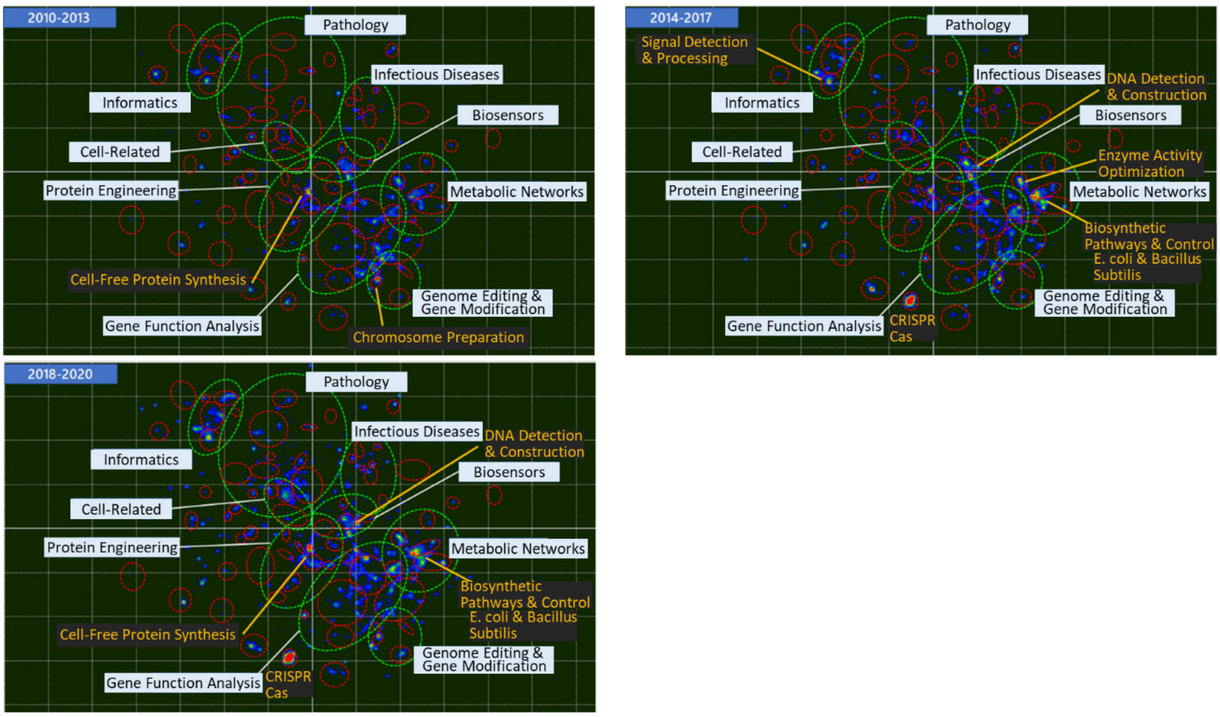


Figure 3-5 Temporal changes in the distribution of papers with synthetic biology-related keywords

In the period from 2010 to 2013, the areas where papers were strongly concentrated were "cell-free protein synthesis" and "chromosome preparation," with other areas sparsely distributed. During the period from 2014 to 2017, strong concentrations were newly observed in categories such as "biosynthetic pathways & control," "E. coli & Bacillus subtilis," "enzyme activity optimization" in the Metabolic Networks category, and "DNA detection & construction" in the Biosensors category, as well as in "CRISPR-Cas" and "signal detection & processing" areas. The strong concentrations continued into the period from 2018 to 2020, especially in "cell-free protein synthesis," "biosynthetic pathways & control," "E. coli & Bacillus subtilis," "CRISPR-Cas," "DNA detection & construction" areas, indicating ongoing research and technology related to synthetic biology in these areas.

Figure 3-6 shows the number of papers containing synthetic biology-related keywords and their recent ratio (limited to those with more than 20 papers). Some papers that include keywords related to synthetic biology, such as DNA data storage, CRISPR-Cas, and multiplexed genome editing, show an increasing trend based on the recent ratio. Especially for keywords with fewer data entries, an increase is expected in the future.

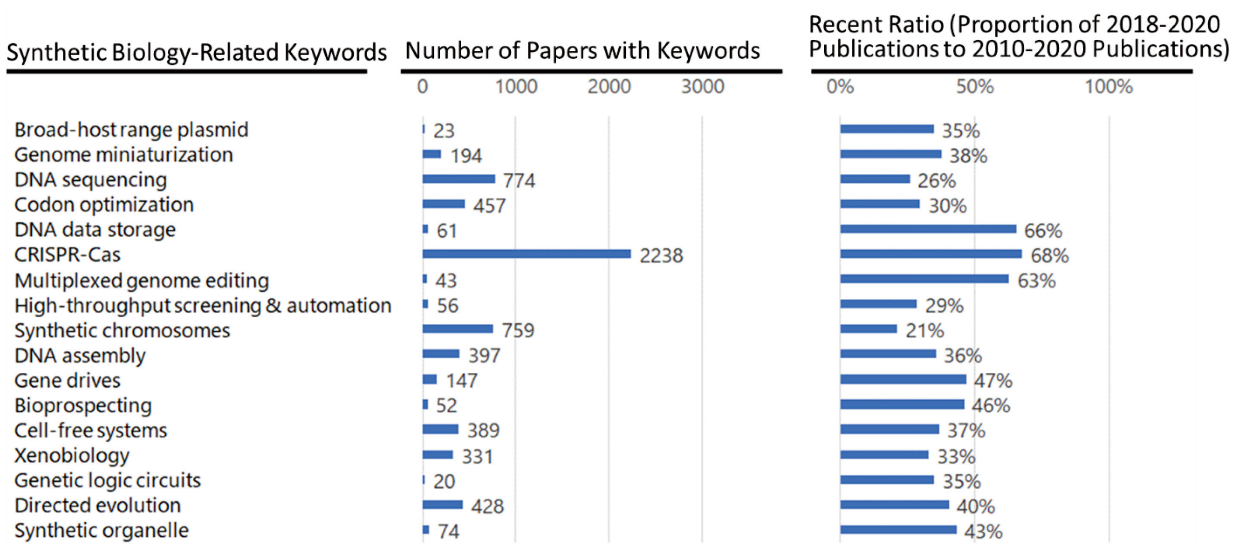


Figure 3-6 Number and recent ratio of papers with synthetic biology-related keywords

3.3 Global Research and Technology Areas Identified by Patent Analysis

3.3.1 Emerging Biotechnology Field

Similar to the analysis method for papers, Figure 3-7 shows the temporal changes in patents related to research and technology transitions in the emerging biotechnology field from 2010 to 2020.

During the period from 2010 to 2013, patents were distributed across a wide range of fields, with a characteristic strong concentration in the "Genome Editing & Gene Modification" category. In addition to technologies related to "Genome Editing & Gene Modification" such as "Primers" and "Nucleic Acid Preparation," there was also a concentration of patents related to emerging biotechnology products, such as "Antibodies."

From 2014 to 2017, in addition to the concentration in the “Genome Editing & Gene Modification” category, new concentrations were seen in the individual areas of “Metabolic Networks,” “CRISPR-Cas,” “E. coli & Bacillus subtilis,” and “Traditional Chinese Medicine”. In the “CRISPR-Cas” and “E. coli & Bacillus subtilis” areas, many patents related to genome editing technology were observed. From 2018 to 2020, excluding the “Informatics” area, the distribution of concentrations was similar to the period from 2014 to 2017, with no significant overall differences.

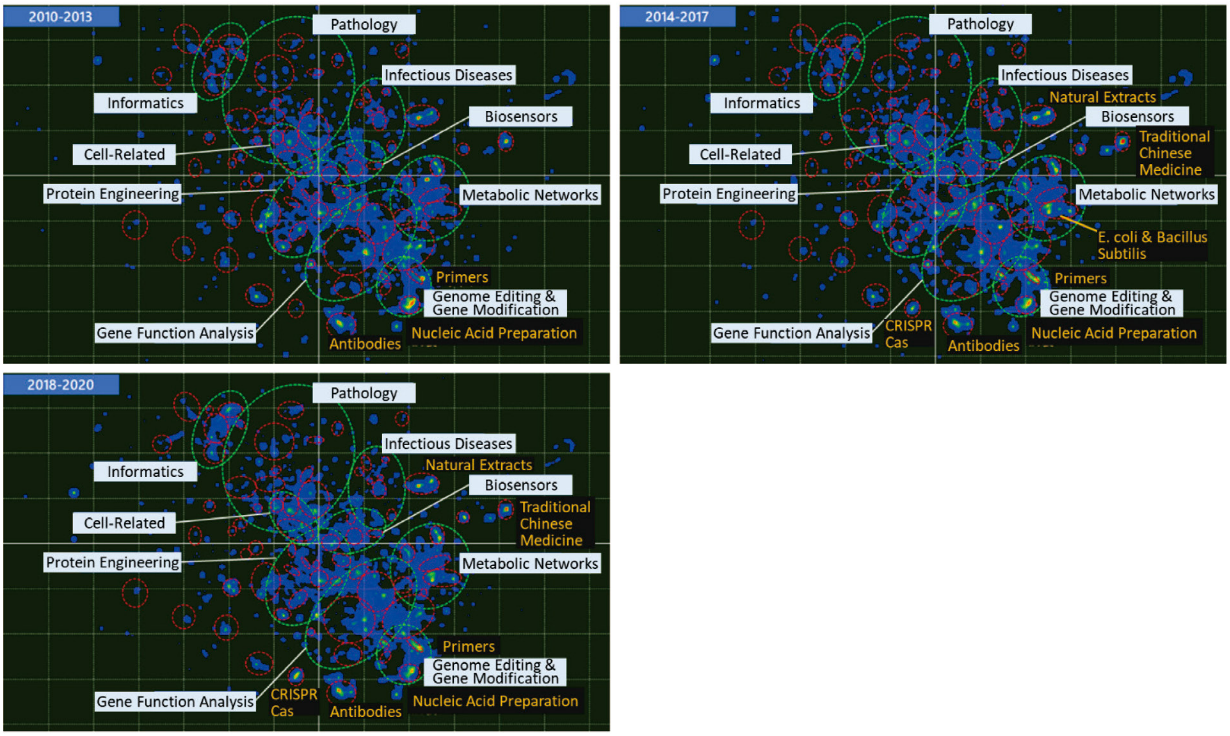


Figure 3-7 Temporal changes in the patent research & technology map

To understand the temporal changes in patent information in more detail, the number of patents by each research & technology category and their recent ratio are shown in Figure 3-8. The category with the most patents is “Gene Function Analysis,” followed by “Protein Engineering” and “Genome Editing & Gene Modification.” These categories have a wide distribution on the research & technology map, indicating that they include various themes with slightly different contents.

On the other hand, like papers, the category with the highest recent ratio is “Informatics,” followed by “Cell-Related” and “Pathology.” The “Informatics” technology area is mainly supported by “Machine Learning,” with a high recent ratio but still a small number of patents. Although there are not many patents for “Informatics” technologies that serve as the foundation for high-throughput automation or systems biology, this category is considered likely to accelerate towards practical applications in the future. Meanwhile, “Cell-Related” and “Pathology” involve many research and technology fields related to medicine, such as “Cell Culture Materials & Preparation” technologies and “miRNA and Diseases,” suggesting that materials and sensing-related technologies may be driving growth, making technology commercialization particularly important in these categories.

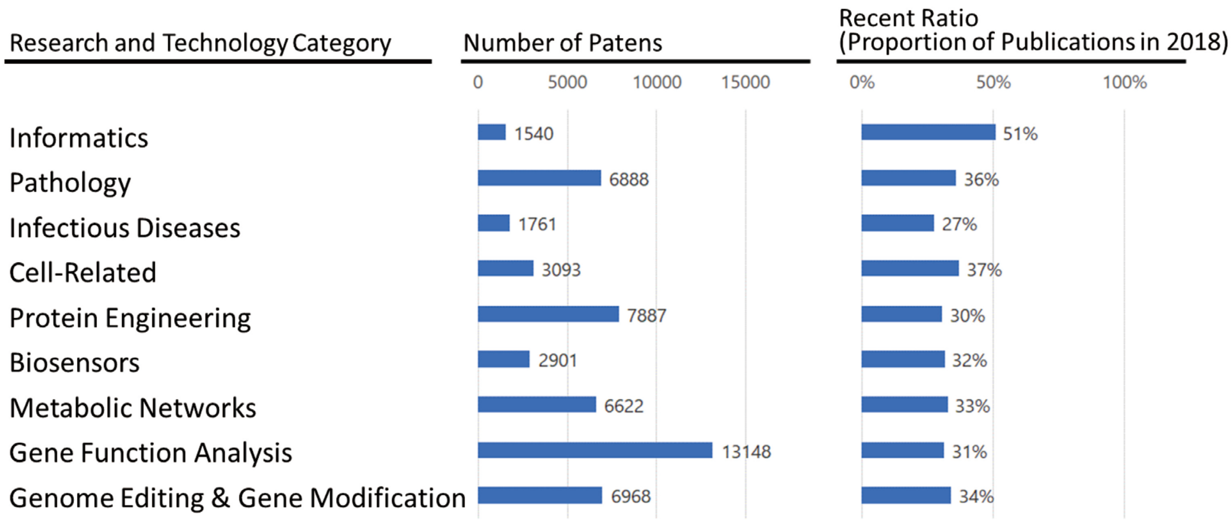


Figure 3-8 Number and recent ratio of patents by each research & technology category

3.3.2 Synthetic Biology Field

Following the same flow as the previous paper analysis, Figure 3-9 shows the results of analyzing the trends of patents related to synthetic biology (limited to patents containing keywords in the title or summary) within the emerging biotechnology field.

Patents containing synthetic biology-related keywords are mostly distributed in "Gene Function Analysis" and its surrounding categories ("Biosensors," "Metabolic Networks," "Genome Editing & Gene Modification (CRISPR-Cas)"), but unlike papers, there is hardly any distribution in "Informatics" and "Protein Engineering" categories. Patents containing synthetic biology-related keywords include many related to metabolic engineering and protein engineering in the "Gene Function Analysis" and "Metabolic Networks" categories, and in the "Biosensors" category, patents related to DNA detection technologies, such as DNA sequencing, similar to papers.

From 2010 to 2013, the area with the strongest concentration of patents was "DNA Detection & Construction," with hardly any distribution in other areas. From 2014 to 2017, new concentrations were seen in "CRISPR-Cas" and "E. coli & Bacillus subtilis," and the same applies to the period from 2018 to 2020.

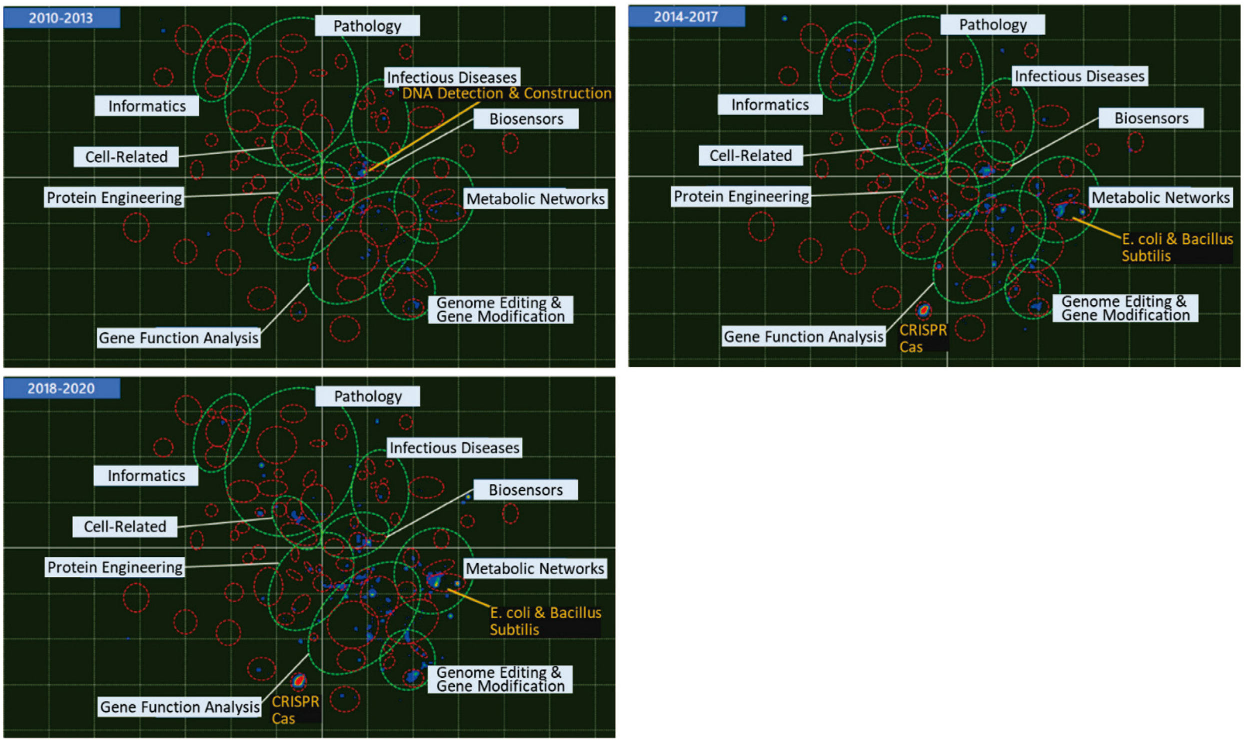


Figure 3-9 Temporal changes in the distribution of patents with synthetic biology-related keywords

Figure 3-10 shows the number of patents containing synthetic biology-related keywords and their recent ratio. Although the numbers are small, patents containing keywords such as DNA data storage, CRISPR-Cas, and multiplexed genome editing also show an increasing trend in the patent analysis, similar to papers, suggesting an increase in research and technology related to synthetic biology from the perspective of patents.

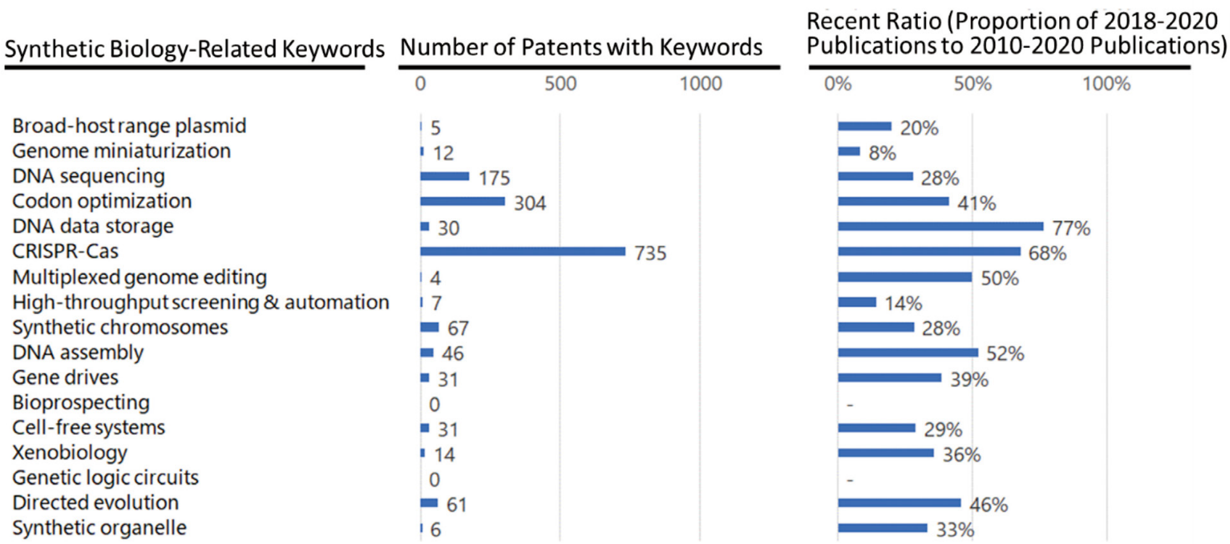


Figure 3-10 Number and recent ratio of patents with synthetic biology-related keywords

3.4 Research and Technology Areas Identified by Paper Analysis by Country

In this section, the number of papers (relative values) for each individual area from 2010 to 2020, as well as the recent ratios, were organized to assess the dominant research and technology areas, their characteristics, and the main research institutions for each individual area[261].

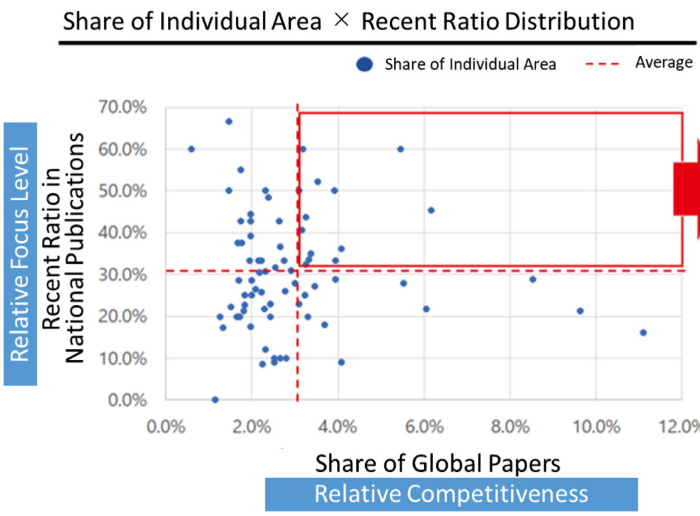
3.4.1 Australia

(1) Relative Dominance in Research and Technology Estimated from Papers

The scatter plot on the left side of Figure 3-11 plots individual areas based on the ratio of Australian paper numbers to the global total on the x-axis and the recent ratio on the y-axis for each individual area. The x-axis serves as an indicator of relative competitive strength, showing the share of paper numbers relative to the global total, while the y-axis serves as an indicator of relative focus, showing the recent number of papers. Individual areas rated above a certain level in both relative competitive strength and focus are considered dominant research and technology fields, and individual areas included in the area (red frame in the scatter plot) with values above the average for all Australian papers are extracted and organized.

“Pathology” and “Protein Engineering,” among others, as well as individual areas related to plant biosynthesis in the “Metabolic Networks” and “Gene Function Analysis” categories, are suggested as dominant research and technology fields. Additionally, in terms of relative values for papers specialized in synthetic biology keywords, “High-Throughput Screening and Automation” and “Gene Drive” had particularly high ratios, suggesting a high proportion of themes related to gene mutation and screening. Meanwhile, “Bioprospecting” and “Directed Evolution” had particularly high recent ratios and considering the increasing number of papers in the “Metabolic Networks” category, there may be a growing interest in metabolic engineering through genome editing.

261 Both Australia and India generally have a low number of patents, making it difficult to identify areas of technological advantage, thus this analysis was excluded. Additionally, detailed information on China’s relative research and technology advantages is omitted.



Individual areas above average in both competitiveness and focus

Major Category	Individual Areas	Relative Competitiveness	Relative Focus Level
Informatics	Machine Learning	3.5%	52.1%
Pathology	Bone Formation	3.3%	43.8%
Pathology	Tumor	3.3%	32.3%
Pathology	Patient Genetic Factors	5.5%	60.0%
Cell-Related	Stem Cell Preparation	3.2%	40.7%
Protein Engineering	Fution Protein	3.3%	33.7%
Protein Engineering	Functional Peptides (Antimicrobial, etc.)	4.1%	36.1%
Protein Engineering	Antigenic Peptides	3.1%	50.0%
Metabolic Networks	Terpene Biosynthesis	3.2%	60.0%
Gene Function Analysis	Plant-Related Gene	3.4%	35.0%
Other	Impact on Feed & Environment	3.9%	33.3%
Other	Mitochondrial Function	6.2%	45.3%
Other	Traditional Chinese Medicine	3.9%	50.0%

Figure 3-11 Relative dominance in research and technology estimated from the number (relative value) and recent ratio of papers by individual area

(1) Major Institutions with Dominance in Research and Technology Based on Paper Information

Table 3-3 shows Australian institutions with a high number of papers in dominant research and technology fields. Among the major institutions, the University of Melbourne, the University of Queensland, the University of Western Australia, and the CSIRO have many papers in the field of synthetic biology. Based on the proportion of papers since 2018, the University of New South Wales is also a noteworthy institution. The University of Melbourne has many papers in the "Informatics" category and "Mitochondrial Function" category, while the University of Queensland has many paper publications in the "Cell-Related" category and "Fusion Protein" area. Although not listed in the table, Macquarie University's COE (2020-) is actively working on synthetic biology for engineering control of wine fermentation tanks, including crowd control and aroma control of wine yeast using synthetic biology and functional analysis of non-*Saccharomyces* yeast (NSY) as co-culture partners for wine yeast. Their future activities appear promising.

Table 3-3 Major institutions with the highest number of papers in the field of emerging biotechnology & synthetic biology

Name	Total number of papers (number with synthetic biology keywords)	Proportion of papers since 2018 (proportion with synthetic biology keywords)
University of Melbourne	132 (26)	49% (50%)
University of Queensland	112 (44)	41% (45%)
Monash University	89 (11)	36% (45%)
University of Western Australia	88 (22)	42% (41%)
University of Sydney	87 (14)	36% (50%)

CSIRO	83 (34)	37% (50%)
University of New South Wales	55 (13)	49% (54%)
Australian National University	41 (11)	39% (45%)

Table 3-4 organizes the proportion of co-authored papers between researchers from major Australian institutions with high numbers of papers in the emerging biotechnology field and researchers from institutions in the United States, China, and Japan, showing that Japan has a lower proportion of co-authored papers compared to the other two countries. Of particular note, the CSIRO (Commonwealth Scientific and Industrial Research Organisation) and the Australian National University have co-authored many papers with China.

Table 3-4 Co-authorship status of major Australian institutions

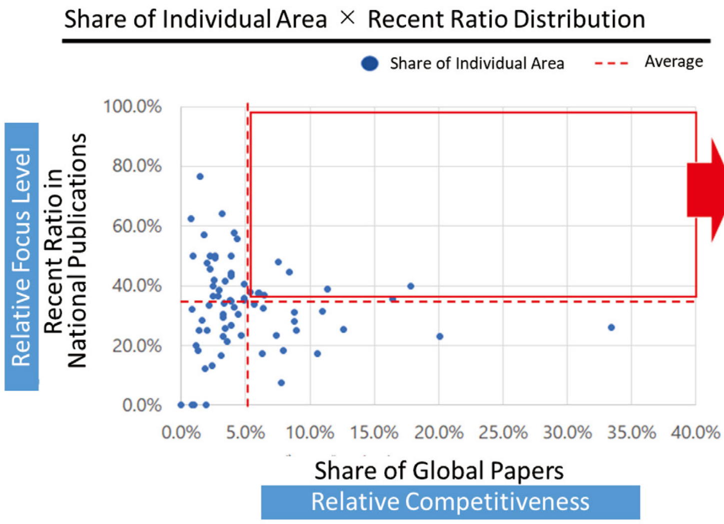
Name	Total number of papers (proportion of papers since 2018)	Proportion of co-authored papers with Japan, the United States, and China (2010-2020)		
		Japan	United States	China
University of Melbourne	132 (49%)	5%	36%	8%
University of Queensland	112 (41%)	4%	26%	13%
Monash University	89 (36%)	8%	19%	13%
University of Western Australia	88 (42%)	2%	16%	11%
University of Sydney	87 (36%)	2%	25%	8%
CSIRO	83 (37%)	2%	6%	16%
University of New South Wales	55 (49%)	2%	27%	9%
Australian National University	41 (39%)	7%	29%	20%

3.4.2 India

(1) Relative Dominance in Research and Technology Estimated from Papers

Similar to Australia, individual areas rated above a certain level in both relative competitive strength and focus are considered dominant research and technology fields, and individual areas included in this area (red frame in the scatter plot) with values above the average for all papers in India are extracted and listed in the right table. "Biosensors" and areas such as "Compound Synthesis & Application" could be seen as dominant research and technology fields.

Additionally, in terms of relative values for papers specialized in synthetic biology keywords, "Bioprospecting" and "Codon Optimization" had high ratios, while "DNA Data Storage," "Multiplexed Genome Editing," and "Synthetic Chromosomes" had particularly high recent ratios, suggesting a gathering interest in DNA construction through genetic engineering.



Individual areas above average in both competitiveness and focus

Major Category	Individual Areas	Relative Competitiveness	Relative Focus Level
Informatics	Machine Learning	7.5%	48.0%
Protein Engineering	Vaccines	6.0%	37.5%
Biosensors	Metal Ion Adsorption	11.4%	38.7%
Biosensors	Nanoparticles	16.4%	35.6%
Metabolic Networks	Enzyme Activity Optimization	5.3%	37.8%
Gene Function Analysis	Plant-Related Gene	6.1%	37.6%
Other	tRNASynthetase	6.5%	36.8%
Other	Compound Synthesis & Applications	17.8%	40.0%
Other	Pro- & Prebiotics	8.4%	44.5%

Figure 3-12 Relative dominance in research and technology estimated from the number (relative value) and recent ratio of papers by individual area

(2) Major Institutions with Dominance in Research and Technology Based on Paper Information

Table 3-5 shows Indian institutions with a high number of papers in dominant research and technology fields. The Council of Scientific & Industrial Research (CSIR), the Indian Council of Agricultural Research (ICAR), the Department of Biotechnology (DBT), and the Indian Institutes of Technology (IITs) are among the top institutions in both emerging biotechnology and synthetic biology fields. The analysis shows that these institutions have published papers across a wide range of fields from 2010 to 2020, but particularly many in the "Gene Interactions & Complexes" area. Limited to papers published from 2018 to 2020, the Indian Institutes of Technology have many papers in the "Informatics" category, specifically in the "Machine Learning" area, as part of DNA data storage research, developing efficient algorithms for storing large amounts of data with few bases, while the Council of Scientific & Industrial Research has papers in areas such as pharmaceutical research using modified yeast and "Plant-Related Genes." Besides the institutions listed in Table 3-5, specifically for synthetic biology papers, the Academy of Scientific & Innovative Research (AcSIR) has 10 papers (70%), the Centre for DNA Fingerprinting and Diagnostics (CDFD) has 8 papers (13%), and the Central Food Technological Research Institute (CFTRI-CSIR) has 8 papers (63%)

Table 3-5 Major institutions with the highest number of papers in the emerging biotechnology & synthetic biology field

Name	Total number of papers (number with synthetic biology keywords)	Proportion of papers since 2018 (proportion with synthetic biology keywords)
Council of Scientific and Industrial Research (CSIR)	264 (52)	31% (37%)
Indian Council of Agricultural Research (ICAR)	137 (25)	41% (40%)

Indian Institutes of Technology (IITs)[262]	110 (25)	45% (36%)
Department of Biotechnology (DBT)	110 (31)	32% (45%)
National Institutes of Technology (NIT)[263]	62 (-)	50% (-)
Banaras Hindu University (BHU)	58 (-)	47% (-)
Department of Science and Technology (DST)	54 (-)	28% (-)
International Centre for Genetic Engineering and Biotechnology (ICGEB)	49 (9)	24% (33%)
Indian Institute of Science, Bangalore (IISC)	44(11)	23% (45%)

Table 3-6 organizes the ratio of co-authored papers between researchers from major Indian institutions in the field of emerging biotechnology and researchers from institutions located in the United States, China, and Japan. India, compared to Australia, tends to have a lower ratio of international co-authorship, with Japan being on a similar level to China in terms of the low ratio of co-authored papers.

Table 3-6 Co-authorship status of major Indian institutions

Name	Total number of papers (proportion of papers since 2018)	Proportion of co-authored papers with Japan, the United States, and China (2010-2020)		
		Japan	United States	China
Council of Scientific and Industrial Research (CSIR)	264 (31%)	1%	6%	3%
Indian Council of Agricultural Research (ICAR)	137 (41%)	1%	3%	0%
Indian Institutes of Technology (IIT)[264]	110 (45%)	3%	8%	1%
Department of Biotechnology (DBT)	110 (32%)	2%	7%	0%

262 The Indian Institutes of Technology (IIT) are the premier institutes of engineering education in India, encompassing 23 universities such as IIT Kharagpur and IIT Bombay.

263 The National Institutes of Technology (NIT) are public technical research institutes owned by the Ministry of Education of the Government of India.

264 The Indian Institutes of Technology (IIT) are the premier institutes of engineering education in India, encompassing 23 universities such as IIT Kharagpur and IIT Bombay.

National Institutes of Technology (NIT)[265]	62 (50%)	0%	6%	2%
Banaras Hindu University (BHU)	58 (47%)	0%	5%	0%
Department of Science and Technology (DST)	54 (28%)	2%	6%	2%
International Centre for Genetic Engineering and Biotechnology (ICGEB)	49 (24%)	4%	4%	2%
Indian Institute of Science, Bangalore (IISC)	44 (23%)	0%	14%	2%

3.4.3 Dominant Individual Areas by Country Based on Number of Papers

So far, the analysis of each country has involved both paper and patent information, but the number of patents in Australia and India is very limited, making it difficult to assess and compare dominant research and technology from a patent perspective. Therefore, themes are organized in Table 3-7 based on the results of the dominance assessment obtained from “number of papers” information.

Comparing Australia, India, and Japan, there are themes such as “CRISPR-Cas,” “cell-free systems,” and “directed evolution” where all three countries have dominance, suggesting they could further enhance this advantage by collaborating. Also, if there are themes where Japan and either Australia or India is dominant, collaboration between the two countries could also potentially enhance their advantage. However, when considering a collaborative relationship that complements the respective dominant fields between Australia and Japan or India and Japan, an approach of collaborating with Australia or India in fields they have dominance in like “codon optimization,” “DNA data storage,” “gene drives,” and “bioprospecting” where Japan does not, is a possibility. Assessing and organizing themes related to synthetic biology in which each country has dominance is an important perspective when considering collaborative strategies.

265 The National Institutes of Technology (NIT) are public technical research institutes owned by the Ministry of Education of the Government of India.

Table 3-7 Themes Related to Synthetic Biology Where Each Country is Dominant Based on Number of Papers[266]

Theme	Dominance by Country (◎ indicates a competitive dominance and focus, ○ indicates a dominance in either)				
	Australia	India	Japan	United States	China
Wide-host-range plasmids	○		◎	◎	
Genome miniaturization			○	◎	
Codon optimization		◎			○
DNA assembly	○		○	○	◎
CRISPR-Cas	○	○	○	◎	◎
Multiplexed genome editing		○	○	◎	◎
Synthetic chromosomes	○		○	○	○
Gene drives	◎			◎	◎
Cell-free systems	○	○	○	◎	○
Directed evolution	○	○	○	◎	○
Synthetic organelles	○		○	○	○
High-throughput screening and automation	◎		○	○	
DNA data storage		○		◎	○
Bioprospecting	○	◎		○	◎
Xenobiology			○	○	

266 “Dominant” here simply refers to assigning ◎ or ○ based on the number of papers, without considering the weight of the authors (First/Last author, etc.). Themes without ○ are those with a low number of papers, such as single digits.

4 Summary

There are still many growth areas and abundant opportunities in the field of synthetic biology and other emerging biotechnologies. However, they require long-term research and development investment and early engagement in research and development. In this environment, the United States, and more recently China and Australia, have been intensively working on policy and strategy formulation and funding in the field of synthetic biology and other emerging biotechnologies, as revealed in this research report.

In all countries researched, the establishment of biotechnology research platforms and clusters, including synthetic biology research, is evident, especially in China, where significant investments are concentrated in Beijing, Shanghai, and the Greater Bay Area. Australia and India also have many policies focused on startup support, opening up well-equipped facilities to research institutions and startups to strongly promote domestic and international collaboration.

Japan’s various ministries are also actively engaging in initiatives under the names of bioeconomy and bioproduction.

However, to acquire research and development capabilities that are on par with the United States, and China, which has rapidly increased its investment in the field of synthetic biology, selective concentration and cooperation strategies with major countries are essential, especially in Japan’s areas of strength, including research equipment and talent development. Furthermore, in the context of pharmaceutical development, which is critical also from the perspective of ensuring supply chain resilience, it is imperative not to overlook the efforts to link research achievements with clinical applications through a clinical testing framework that integrates research results into societal implementations.

Specifically, Japan is known for some outstanding technologies, such as cell-free protein synthesis, but apart from Kobe University, it has no prominent research platforms, and industrial application examples are limited. In a field where global competition is so striking, and the pace of technological advancement is so fast, as demonstrated by the emergence of new technologies such as artificial custom cells, bio 3D printers, molecular robotics, and DNA storage, it is hoped that Japan will focus on strengthening research platforms and intensify joint research with top-level research institutions abroad in mutually beneficial areas.

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5 APPENDIX

5.1 Main Synthetic Biology Related Keywords and Glossary

Based on various materials, the JST Asia and Pacific Research Center has organized and summarized the main keywords related to synthetic biology in Table A-1. These keywords serve as basic information for paper and patent searches.

Table A-1 Main Synthetic Biology Related Keywords and Glossary

Classification	Synthetic Biology Related Keywords	Overview
Targets & Tools	BioBrick (BioBrick)	Standardized synthetic DNA parts (components) with certain functions and structures. Proposed by Professor Tom Knight, a synthetic biologist from the USA (Ginkgo Bioworks). Catalogs of each part are available on the iGEM website.
	Broad-host-range plasmids (Broad-host range plasmid)	Plasmids are circular DNA found in bacteria. Broad-host-range plasmids play an important role in horizontal gene transfer. In addition, their replicons are suitable for vector construction.
	Minimal genome (Minimal genome)	A streamlined genome that is minimized to the essentials necessary for maintaining life functions.
	Synthetic cells (Synthetic cell)	Synthetic cells refer to entities assembled from molecules that have been either broken down and extracted from biological cells or synthetically created, incorporating new blueprints that do not exist in nature.
	Synthetic chromosomes (Synthetic chromosome)	A representative example of synthetic chromosomes is the research on yeast chromosome reconstitution using the SCRaMbLE system in the yeast genome synthesis project (Sc2.0) reported by Professor Jef Boeke of New York University in 2018.
	Synthetic organelles (Synthetic organelle)	Artificially created cell organelles such as nuclei, mitochondria, and Golgi bodies. It is hoped they will have practical applications in fields such as cell therapy.
Modification and synthesis technologies	3D Bioprinting (3D Bioprinting)	A technology that uses 3D printer technology to mimic the structure of proteins, cells, or three-dimensional tissues and organs and construct similar functions and structures. Used in medical and tissue engineering fields.

	Biofabrication (Biofabrication)	Synonymous with 3D bio-printing.
	Bioprospecting (Bioprospecting)	The process of finding useful genetic resources for pharmaceuticals, chemicals, food, etc., from biological resources.
	Codon optimization (Codon optimization)	Designing an introduced gene sequence appropriately to improve production yield when producing proteins not originally present, such as by introducing genes from different host species.
	Cell-free systems (Cell-free systems)	Cell-free protein synthesis systems are efficient technologies for synthesizing recombinant proteins. They are based on cell extracts from E. coli, wheat germ, human cell lines, etc., performing RNA transcription to protein synthesis.
	CRISPR-Cas	A genome editing technology that artificially modifies the genome of organisms, awarded the 2020 Nobel Prize in Chemistry. Development of nucleases different from Cas9 is progressing due to issues with PAM sequence specificity and vector size. Professor Jennifer Doudna at UC Berkeley is working on genome editing using the small Cas Φ .
	DNA origami (DNA origami)	A molecular design and fabrication method that mixes one long single-stranded DNA with a vast number of short single-stranded DNAs to create various nanostructures.
	Directed evolution (Directed evolution)	An experimental method of the 2018 Nobel Prize in Chemistry, mimicking natural evolution and selection, changing the function of proteins, DNA, etc., through PCR.
	Genome miniaturization (Genome miniaturization)	A method to improve gene manipulation efficiency and enable high-throughput screening by retaining only the minimal genome necessary for maintaining functions.
	Genetic logic circuits (Genetic logic circuits)	Research incorporating various artificial circuits into cells like electrical circuits. In 2007, groups including Professor Christopher Voigt of UCSF (at the time) and Dr. Adam Arkin of Lawrence Berkeley National Laboratory demonstrated circuits that accurately switch genes using AND gates in E. coli. In 2013, Professor Timothy Lu of MIT and Dr. Drew Endy of Stanford University developed logic gates using site-specific recombinases, showing significant progress.
	Gene drives (Gene drives)	A technique that introduces the CRISPR/Cas9 genome editing system itself into the genome to completely modify all offspring's target genes.
	Metabolic engineering (Metabolic engineering)	A field of study related to the modification and analysis of biological metabolic pathways.

	Multiplexed genome editing (Multiplexed genome editing)	A multiplex CRISPR technology that expresses numerous gRNAs and Cas enzymes at once. Greatly improves the scope and efficiency of genome editing and transcriptional regulation.
	Microbiome engineering (Microbiome engineering)	Engineering modifications to the microbiome to alter the structure (bacterial species balance) and function of microbial communities within the gut flora and ecosystems.
	Protein Engineering (Protein engineering)	Artificially modifying and creating new proteins based on natural substances.
	Riboswitch (Riboswitch)	Sequences in the untranslated region of mRNA that regulate the expression of the genes they carry.
	Self-organizing multicellular structures (Self-organizing multicellular structure)	The process in the fabrication of biomaterials or artificial tissues where single cells autonomously organize (self-organize) over time to form multicellular 3D structures.
Design/Evaluation Technologies	DNA sequencing (DNA sequencing)	Determining the sequence of bases (adenine (A), thymine (T), guanine (G), cytosine (C)) in DNA.
	DNA assembly (DNA assembly)	In bioinformatics, computer processing that reconstructs genome sequences by connecting a large number of DNA fragment sequences.
	High-throughput screening and automation (High-throughput screening and automation)	Automating the testing of the utility of compounds in experiments and drug discovery processes using robots, etc.
	Modeling, machine learning (Modelling, machine learning)	Promising sequence detection, statistical learning, reinforcement learning, structure prediction, optimal pathway calculation, and structured/quantitative design of life dynamics, etc.
	Organ-on-a-chip Organs-on-Chips	Microfluidic chips/devices that mimic organs. Contribute to accelerating drug discovery, etc.
Applied and related terms	Biofoundry (Biofoundry)	A bio-production system for culture, transport, and contract manufacturing.
	Bioeconomy (Bioeconomy)	The concept of utilizing biotechnology and renewable biological resources to expand a sustainable, renewable circular economy.
	DNA data storage (DNA data storage)	A technology that uses DNA as an information storage medium. Expected to allow for high-density, long-term data storage. The idea was originally proposed by a group at Mount Sinai School of Medicine in the USA in 1999.
	Engineering biology (Engineering biology)	Synonymous with synthetic biology. Refers to an interdisciplinary field that enables the prediction of modifications to life systems, their components, and biological processes.

	Systems biology (Systems Biology)	Research that views the networks of genes, proteins, metabolites, and cells as life systems, exploring how their functions are regulated and how they respond to perturbations. Also synonymous with life dynamics.
	Xenobiology (Xenobiology)	A field aimed at designing artificial life forms not found in nature, such as by replacing parts of nucleic acids with synthetic polymers. Said to intersect the origins of life, astrobiology, synthetic biology, and systems chemistry

5.2 Japan-Australia Synthetic Biology Workshop (Held online on March 16, 2022)

On March 16, 2022, the JST Asia and Pacific Research Center (JST APRC), in cooperation with JST’s International Division, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Australian Government Department of Industry, Science, Energy and Resources (DISER), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Australian Embassy in Japan, hosted a workshop titled “Future Trends and Emerging Technologies in Synthetic Biology - Connecting Australia and Japan through science and technology.” This workshop aimed to provide networking opportunities for researchers in the field of synthetic biology from Japan and Australia, hoping to lead to future international joint research. In this workshop, chaired by Professor Akihiko Kondo (Vice President of Kobe University) from the Japanese side and Dr. Claudia Vickers (CSO of Provectus Algae Pty Ltd.) from the Australian side, more than 150 participants shared research outcomes and the latest information on synthetic biology, with 14 speakers presenting.

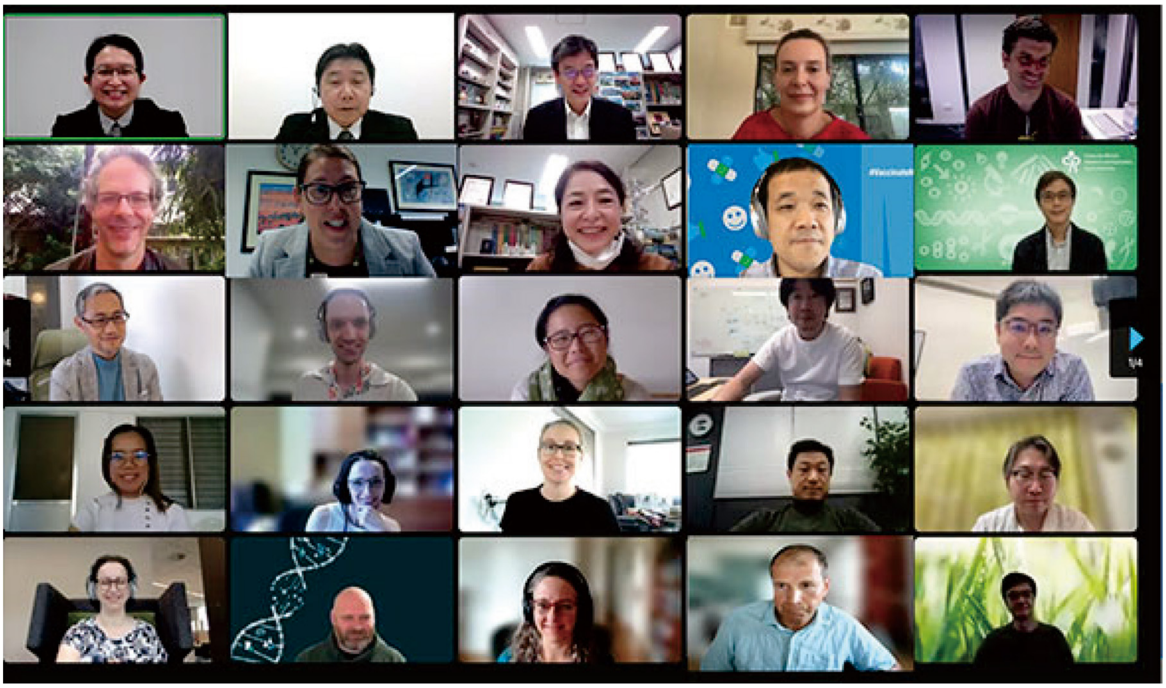
Keynote speeches included a lecture from Professor Aleksandra Filipovska, Deputy Director of the Australian Research Council Centre of Excellence in Synthetic Biology (ARC Synthetic Biology COE), on mitochondrial RNA editing tools and their medical applications, and a presentation by Professor Hiroyuki Noji from the University of Tokyo on artificial cell reactor technology and on-chip cell-free systems. In the three sessions, 12 researchers from Japan and Australia gave lectures on the construction of artificial cells and fundamental technologies of synthetic biology, systems biology and protein translation systems, and applied research in synthetic biology. These sessions were followed by energetic Q&A sessions.

The final discussion session focused on metabolic engineering, systems biology & modeling, data science and bioinformatics, artificial cells, and genome engineering, bioproducts and biomaterials, cell-free systems, protein engineering, and biocatalysis. Speakers and participants divided into three groups discussed the characteristics and deficiencies of research in Japan and Australia, and discussed potential areas for future joint research, summarized in Table A-2.

Table A-2 Areas of Expected Joint Research Discussed in the Workshop

Country	Strengths	Weaknesses	Expected Applications/ Industrial Fields
Japan	- Artificial cell simulation - Genome reconstruction - In vivo tissue engineering - Enzyme engineering, such as fermentation - Artificial membranes - Exploration of metabolic pathways - Plant hormone research (RIKEN Center for Sustainable Resource Science, CSRS) - Lab automation (strengths in basic research)	- Despite having a unique community, tends to be isolated from other regions, lacking visibility in international major projects - Synthetic biology perceived merely as "synthesis", whereas in the US it is strongly associated with information science - Cross-disciplinary efforts are lacking compared to the West	Genetically modified crop field trials or edible chemical production
Australia	- Systems biology - Protein simulation in drug discovery (AI platforms) - Molecular docking dynamics (applied research-oriented) - Protein engineering (enzyme engineering and sensors)	- Exploration of metabolic pathways - Research development using AI	Sustainable agriculture Medical fields Metabolic engineering for industrial material discovery Gene editing in plants

- Primary Areas and Challenges Proposed for Joint Research in the Discussion Session
  - ✓ Whole-cell simulation
  - ✓ Biohydrogen energy production
  - ✓ Biomaterials (biocompatible materials, biomimetic materials)
  - ✓ Artificial membrane & protein research
  - ✓ Bioparts (BioBricks, etc., from DNA to tissues) and their design research
  - ✓ Non-membrane organisms - Control of rotation centered on ATP
  - ✓ Biofoundry foundational technologies (biomanufacturing)
  - ✓ Metabolic modeling - Reverse synthetic pathway search: databases, algorithms/modeling



- Workshop Program & Abstracts

Future Trends and Emerging Technologies in Synthetic Biology

Connecting Australia and Japan through science and technology

1. **Date: Wednesday, 16th March 2022, 10:00 ~ 16:00 (AEST) / 9:00 ~ 15:00 (JST)**
2. **Zoom Meeting**
3. **Language**: English
4. **Target Audience**: Australian and Japanese representatives of research performing organizations, researchers, students in the field of synthetic biology, policymakers, etc.
5. **Co-chaired by**:

   Akihiko Kondo, Vice President, Kobe University

   Claudia Vickers, Chief Scientific Officer, Provectus Algae; Adjunct Professor, Queensland University of Technology; Adjunct Professor, Griffith University
6. **Program**

10:00 AEST / 09:00 JST	**Welcoming Remarks** · **Hiroya YAMANOUCHI**, Director, Office for Strategic Research Promotion, Strategic Planning, Research and Development Division, Science and Technology Policy Bureau, MEXT · **Steph Gorecki Natik**, General Manager of the International and Astronomy Branch, DISER
10:15 AEST / 09:15 JST	**Part 1: Morning part** **Chair: Akihiko Kondo**, Vice President, Kobe University
	Keynote speech “Medicinal Synthetic Biology” **Aleksandra Filipovska**, Deputy Director, the ARC Centre of Excellence in Synthetic Biology; Professor, University of Western Australia Keywords: energy metabolism, mitochondria, gene editing
10:35 AEST / 09:35 JST	**Session A: Artificial cell construction, Basic technology** · **Yuki Goto**, Associate Professor, the University of Tokyo **Artificial in vitro biosynthesis of backbone-modified peptides toward development of pseudo-natural products** Keywords: In vitro translation, posttranslational modification, macrocyclic peptides, natural products, in vitro selection, mRNA display · **Hirohide Saito**, Professor, the Center for iPS Cell Research and Application, Kyoto University **RNA and RNP synthetic biology to expand the possibility of synthetic living systems** Keywords: RNA and RNP synthetic biology, cell programming, microRNA, mRNA, translation · **Wenlong Cheng**, Professor, Monash University **Gold electronic skins and tattoos for connected healthcare** Keywords: Electronic skin, wearable sensors, bioelectronics, gold nanowires · **Ian Paulsen**, Director, ARC Centre of Excellence in Synthetic Biology; Macquarie University **The ARC Centre of Excellence in Synthetic Biology- Inspired by Nature, Designed by Science**

11:35 AEST / 10:35 JST	Session B: Systems biology, Protein translation systems · **Colin Jackson**, Professor, the Australian National University **How the study of protein evolution can aid protein engineering** Keywords: Protein Engineering, Molecular Evolution, Biocatalysis, Computational Protein Design, Bioremediation. · **Kirill Alexandrov**, Professor, Queensland University of Technology **Artificial protein allostery and construction of synthetic logic networks** Keywords: protein allostery, protein biosensors, signaling networks, protein ligand interactions, directed evolution · **Yutetsu Kuruma**, Associate Professor, Earth-Life Science Institute, Tokyo Institute of Technology **Cell-free construction of cellular functions towards artificial cell construction** Keywords: Artificial cell, Cell-free system, Giant vesicle, Membrane proteins, Origin of life · **Nozomu Yachie**, Associate Professor, Canada Research Chair (Tier 2) in Synthetic Biology, University of British Columbia **HD Video Recorder of the Cell** Keywords: DNA event recording, cell lineage tracing, genome editing, base editing, high-performance computing
12:35 AEST / 11:35 JST	Lunch
13:30 AEST / 12:30 JST	**Part 2: Afternoon part** **Chair: Claudia Vickers**, Chief Scientific Officer, Provectus Algae
	Keynote speech 2 “Perspectives on building of autonomous cell systems based on femtoliter reactor technology” **Hiroyuki Noji**, Professor, The University of Tokyo Keywords: Femtoliter reactor technology, On-chip cell-free systems
13:50 AEST / 12:50 JST	Session C: Application · **Keiji Nishida**, Deputy Director, Research Center for Advanced Bioengineering, Kobe University; Bio Palette Inc. **Development and application of base editing technologies** Keywords: Genome editing, Base editing, CRISPR, Breeding · **Toshiya Muranaka**, Professor, Osaka University **Towards development of new varieties of plants with medicinal properties by synthetic biology** Keywords: Convention on Biological Diversity (CBD), genome editing, plant specialized metabolites, medicinal plants, synthetic biology · **Colin Scott**, Synthetic Biology Future Science Platform Leader, CSIRO **Artificial metabolic pathways in continuous-flow** Keywords: Enzyme fusion, modified cofactors, continuous flow biocatalysis · **Claudia Vickers**, Chief Scientific Officer, Provectus Algae; Adjunct Professor, Queensland University of Technology; Adjunct Professor, Griffith University **Synthetic biology tools to understand and control subcellular biocatalysis conditions** Keywords: Isoprenoids, nanotechnology, virus-like particles, biosensors, metabolic engineering

14:50 AEST / 13:50 JST	**Discussion Session**		
	Session 1	**Session 2**	**Session 3**
	· Metabolic engineering · Systems biology and modeling, Data science and bioinformatics · Application	· Artificial cells and genome engineering · Synbio tools and nanotechnology · Application	· Bio-products and bio-materials · Cell-free systems, Protein engineering, Biocatalysis · Application
15:35 AEST / 14:35 JST	Wrap-up session by co-chairs: **Akihiko Kondo, Claudia Vickers**		
16:00 AEST / 15:00 JST	Close		

DISCUSSION SESSION

1. Discussion session’s length: approx 45mins. There are chair and co-chair for each session. Chair will moderate the session and co-chair will do the summarize at the end.
2. Questions
   - What are the strengths in the discussion fields in Australia and Japan? What are the weaknesses?
   - Where are the obvious areas for collaboration? – i.e. a strength in one country that compliments a weakness in another country
   - What are the strategic and exciting new technical directions these technologies will move in?
   - What application areas are strategic priorities for each country? How can we help support technology development in these areas?
   - Given the various international frameworks and the fact that some countries, such as Europe and the United States, are becoming more active in research, what issues need to be addressed to stimulate joint research between Japan and Australia further?

Session 1	Session 2	Session 3
· Metabolic engineering · Systems biology and modeling, data science and bioinformatics · Application	· Artificial cells and genome engineering · Synbio tools and nanotechnology · Application	· Bio – products and bio – materials · Cell - free systems, Protein engineering, Biocatalysis · Application
Chair: Claudia Vickers **Co-chair:** Nozomu Yachie	**Chair:** Hiroyuki Noji, **Co-chair:** Ian Paulsen	**Chair:** Colin Scott **Co-chair:** Yuki Goto
Toshiya Muranaka Nozomu Yachie Yutetsu Kuruma Claudia Vickers	Hiroyuki Noji Keiji Nishida, Hirohide Saito Ian Paulsen Aleksandra Filipovska	Akihiko Kondo Yuki Goto Colin Scott Kirill Alexandrov Colin Jackson

5.3 Policies of Major Provinces and Cities Based on China’s 14th Five-Year Plan

Table A-3 Promotion of Synthetic Biology Research in Various Provinces and Cities Based on China’s “14th Five-Year Plan”

Date	Province/ City	Policy Name	Descriptions Related to Synthetic Biology in the Policy (Excerpt)
June 11, 2021	Zhejiang Provincial People’s Government	The 14th Five-Year Plan for the Development of Scientific and Technological Innovation in Zhejiang Province[267]	Further implement innovation-driven development strategies and accelerate the construction of higher education facilities. 2. Tackle fierce competition in the development of key core technologies (1) Main Issues Focus on basic research in intelligent computing, new generation communication networks, new generation smart chips, quantum information, precision medicine, new drug creation and medical devices, cutting-edge new materials, precision manufacturing, low-carbon energy, green chemicals, environmental governance, biological characteristics of agriculture, marine resource development and disaster prevention, mathematical mechanics, etc.
August 4, 2021	Shanxi Provincial People’s Government	Shanxi Province 14.5 14 Strategic Emerging Industries[268]	III. Overall Requirements (III) Development Goals By 2025, to have industrial clusters with high market share and strong competitiveness, among which 3 to 5 strategic emerging industry clusters such as big data and semiconductors will become the new economic pillars of the province, complete national-level research and development manufacturing bases for carbon-based new materials, special metal materials, and synthetic biology industries, significantly improving the province’s industrial base capability and the modernization level of the industrial chain. [...] IV. Development Focus (VIII) A New Materials Industry Based on Biotechnology Advance basic research in synthetic biology and developing applied technologies based on biotechnology, such as high-performance new polymers and biomimetic materials. Accelerate the construction of key projects like synthetic biology industrial ecology parks and biodegradable polyesters while focusing on the development of products such as bio-based polyamides, biodegradable polyesters, and bio-carbon fiber composite materials.

267 浙江省人民政府,“浙江省科技创新发展“十四五”规划,”: http://kjt.zj.gov.cn/art/2021/8/6/art_1229247517_4698825.html. [Accessed January 2022].

268 山西省人民政府,“山西省「14・5」14の戦略的新興産業計画,”: http://www.shanxi.gov.cn/sxszfxxgk/sxsrmzfzcbm/sxszfbgt/flfg_7203/szfgfxwj_7205/202107/t20210706_926554.shtml [Accessed January 2022].

August 8, 2021	Tianjin Municipal People's Government of Hebei Province	The 14th Five-Year Plan for Science and Technology Innovation in Tianjin[269]	Chapter 1.1 Assessing New Trends in Technological Innovation and Development (1) Current Situation Since the 13th Five-Year Plan, the city has actively implemented the innovation-driven development strategy, and support for scientific and technological innovation has achieved remarkable results in promoting social and economic development. [...] Major platforms such as large-scale earthquake engineering simulation research facilities and the national synthetic biology innovation center were constructed, and achievements were made in key areas such as artificial intelligence, biomedical, new materials (such as precise customization synthesis of yeast chromosomes). Chapter 2 1. Active Deployment of Applied Facilities and Cutting-Edge Technologies - Promote collaborative innovation in Beijing-Tianjin-Hebei (e.g., "Cell Valley", "Bio-Manufacturing Valley") 2. Efforts to Promote Core Technology Research (2) Biotechnology and Modern Medicine Focus on the development of synthetic biology, new generation DNA synthesis, gene editing, artificial design of protein modules, genetic network design, digital cell modeling and simulation, design optimization of chassis cells, artificial gene synthesis and assembly, and other technological research. Emphasize supporting the design and construction of high-value compound and natural product biosynthesis pathways, bio-sensing and environmental restoration, biological utilization of CO2, diagnosis/treatment of major diseases, and the development of synthetic biology-based DNA information storage technology.
September 22, 2021	Guangdong Provincial People's Government	The 14th Five-Year Plan for Science and Technology Innovation in Guangdong Province[270]	Chapter 2 2. Promoting the Construction of Major Science and Technology Infrastructure and Clusters In the field of life sciences, the construction of the second phase of the National Gene Bank, a major scientific and technological infrastructure for synthetic biology research, is being accelerated, and in the fields of brain analysis and material science, the second phase construction of the China (Dongguan) Spallation Neutron Source is being accelerated. Chapter 3.2 Strengthening Research on Frontier and Disruptive Technologies Special projects on cutting-edge and disruptive technologies in key areas will be implemented. Synthetic Biology

269 天津市人民政府, "天津市科技创新"十四五"规划,": http://www.tj.gov.cn/zwgk/szfwj/tjsrmzfbgt/202108/t20210812_5532506.html [Accessed January 2022].

270 広東省人民政府, "广东省科技创新"十四五"规划,": http://dara.gd.gov.cn/attachment/0/467/467916/3577549.pdf [Accessed January 2022].

			Research will be conducted on the design of artificial life forms at the intracellular, single-cell, and multicellular levels, improving the quantitative and predictable design capabilities of synthetic biological systems. Research will be conducted on artificial genome design, optimized synthesis and design techniques, gene editing technologies, etc., and high-throughput, automated, and standardized synthetic biotechnology systems will be built. Major artificial biological systems will be constructed to promote disruptive advanced technologies, innovations, and engineering applications of synthetic biology in industrial biointelligence, diagnostics and therapeutics, environmental conservation, energy security, and national security sectors. Research and development will be conducted on the creation and application of industrial enzymes, construction of industrial microbial strains for biomanufacturing, and the application of raw materials for biomanufacturing.
September 2, 2021	Jiangsu Provincial People’s Government	The 14th Five-Year Plan for Scientific and Technological Innovation in Jiangsu Province[271]	Implement an innovation-driven development strategy and accelerate the building of a province strong in science and technology towards realizing the new mission and requirements of “setting an example and leading the front.” According to the plan, establish an industrial technology innovation center with global influence. The following are excerpts specifically related to synthetic biology: (1) Strengthen basic research and innovation: Strategic key research topic No.13 Synthetic Biology (3) Develop high-efficiency, safe, and ecological modern agricultural technologies [...] Strengthen research in synthetic biology, smart agriculture, and bottleneck technologies, accelerate the development of key technologies for green agriculture, promote the construction of agricultural high-tech industry demonstration zones, improve agricultural system services, and enhance quality, efficiency, and competitiveness.
September 28, 2021	Shanghai Municipal People’s Government	The 14th Five-Year Plan for Building a Science and Technology Innovation Center in Shanghai with Global Influence[272]	The construction of a science and technology innovation center with global influence is an important task and strategic mission given by the Central Committee of the Communist Party to Shanghai, serving as a significant driving force for accelerating high-quality socio-economic development and enhancing the city’s energy level and core competitiveness, with science and technology being a crucial support. (4) Strengthening Basic Research 4. Synthetic Biology and the Creation of Life

[271] 江蘇省人民政府,“江苏省“十四五”科技创新规划:,”: http://kxjst.jiangsu.gov.cn/art/2021/9/15/art_83527_10030709.html.

[272] 上海市人民政府,“上海市建设具有全球影响力的科技创新中心“十四五”规划,”: https://www.shanghai.gov.cn/nw12344/20210928/5020e5fdf5ac4c6fb4b219da6bb4b889.html.

			Achieve breakthroughs in artificial biosynthesis systems and build biomanufacturing science and technology and innovative strategic emerging industries, significantly strengthening the international competitiveness of synthetic biology. - Promote interdisciplinary research, including the design of artificial life, biosynthesis of drugs, efficient synthesis of drugs with new structures and functions, and breakthroughs in bioremediation. - Develop unique technologies in gene editing, DNA assembly, and directed evolution to build efficient artificial biological manufacturing systems. - Explore new directions such as semiconductor synthetic biology and functional microbial robots. (5) Implement Strategic Projects in Frontier Areas 14. Cell-Electronic Hybrid Systems Research and development of semiconductor synthetic biology technologies, self-driven chip intelligent sensor systems (ISS), promote the development of intelligent electronic diagnostic and therapeutic systems, early detection of drugs and high-throughput screening, personalized medicine, new microbiological drivers (robots), and other applied research. Note: In addition to vaccine manufacturing, organ 3D printing, etc.
October 18, 2021	Shenzhen Guangming District Government	Measures for the Integrated Development of a Synthetic Biology Innovation Chain Industry in Shenzhen Guangming New District[273]	Support the construction of the synthetic biology industry chain by providing temporary incentives to national high-tech enterprises, enhancing the nurturing of high-tech enterprises, rent subsidies, entrepreneurship space support, etc. Additionally, support the construction of the synthetic biology industry’s ecology by providing event subsidies covering 50% of the costs, supporting journals in the field of synthetic biology selected for “Double High Journals,” associations, think tanks, etc.
October 20, 2021	Hubei Provincial People’s Government	The 14th Five-Year Plan for Science and Technology Innovation in Hubei Province[274]	Chapter 4 Establishing Unique Domestic Sources of Innovation 4. Enhancing the Support and Guarantee Capacity of Basic Research Platforms Promote the construction of research bases in basic fields. [...] Focus on transformative technologies such as neuroscience research, synthetic biology, magnetic confinement fusion, etc., conduct cutting-edge cross-disciplinary basic research, and promote disruptive technological innovation.

273 深圳市光明区政府, “深圳市光明区关于支持合成生物创新链产业链融合发展的若干措施,”: http://www.szgm.gov.cn/xxgk/xqgwhxxgkml/zcfg_116521/qgfxwj/content/post_9261919.html.

274 湖北省人民政府, “湖北省科技创新“十四五”规划,: http://www.hubei.gov.cn/zfwj/ezf/202110/t20211020_3818129.shtml

			Strengthen the construction of science and technology facility platforms. Emphasize ecosystem conservation, modern agriculture, climate change, disaster prevention and management, establish numerous state-level outdoor scientific observation research bases, and promote the establishment of national outdoor scientific observation research bases. [...] Collect, classify, preserve, and utilize human genes, microbial strains, plant strains, viruses, and other resources, and operate high-level natural science and technology resource banks such as the Wuhan National Human Genetic Resources Bank, a germplasm resources bank, and a microbial bacterium (toxin) species collection center, among others.
November 3, 2021	Beijing Municipal People's Government	Beijing's 14.5 Period International Science and Technology Innovation Center Construction Plan[275]	4. Strengthen unique cutting-edge scientific and technological research, and bravely undertake important tasks relating to major core technologies (2) Promoting Cutting-Edge Technologies in Key Areas Support research and development in cutting-edge biotechnology fields. Generate unique discoveries in the fields of nucleic acid and protein detection, detection of cell functions and pathological change, novel *in vivo* intervention technologies, new antibody technologies, gene editing, novel cell therapies, stem cells, and regenerative medicine. Establish accurate diagnostics and groundbreaking treatments for major epidemics and challenging, rare diseases. (4) Promotion of Other Frontier Areas Promote innovative research in biological breeding. Centered on multi-dimensional omics research, acquire key genes and genetic resources. Focus on the research and development of many important technologies such as efficient genetic transformation technology, precise gene editing, synthetic biology, etc., build the latest biological breeding systems, cultivate (culture) many major new species and varieties, ensuring food security.
February 22, 2022	Anhui Provincial People's Government	14.5 Science and Technology Innovation Plan of Anhui Province[276]	Chapter 3: Supporting Science and Technology for Improving Quality of Life Item 7: Major Technical Projects and Key Topics in the Field of Social Development Key Topic 5: Protein Cell Engineering Technology Focus on the development of key technologies such as AI design of protein structures, efficient expression of fusion protein pharmaceuticals, screening, and humanization of nanobodies, synthetic biology and cell factories, targeted delivery of nucleic acid pharmaceuticals by liposomes, stem cell therapy, organoid construction, 3D printing of biological tissues, etc.

275 北京市人民政府,"北京市"十四五"时期国际科技创新中心建设规划,: http://www.beijing.gov.cn/zhengce/zhengcefagui/202111/t20211124_2543346.html

276 安徽省人民政府,"安徽省"十四五"科技创新规划,": http://fzggw.ah.gov.cn/public/7011/146472951.html.

5.4 China’s National Key Research and Development Programs “Synthetic Biology” and “Green Bio-manufacturing”

According to “Several Opinions on Improving and Strengthening the Management of the State Council’s Central Financial Research Projects and Funds,” “Notice of the State Council on Deepening the Reform Plan for the Management of Central Financial Science and Technology Plans (Special Projects, etc.),” “Interim Measures for the Operation of National Key Research and Development Projects,” etc., the list of key special projects in the field of synthetic biology approved in the fiscal year 2021 is as follows [277][278]. In the field of green bio-manufacturing[279], as part of the 2022 call for proposals, the category of “bounty system (揭榜挂帅)” is soliciting innovative proposals from young researchers, with a large project budget of 35 million yuan (about 665 million yen) over three years. Fields for which proposals are being accepted include reduced carbon emissions through bioenergy and the development of core technologies in energy-saving production processes.

A review of the program shows that the Shenzhen Institute of Advanced Technology (SIAT) of the Chinese Academy of Sciences has been approved for seven out of 25 projects in the synthetic biology field, accounting for a quarter of all projects. Additionally, when including institutions such as universities in Guangdong Province where SIAT is located (Guangdong Institute of Microbiology, Shenzhen University, Sun Yat-sen University), nearly half of the total, 11 out of 25 cases, are occupied by research institutions in Guangdong Province. The approved fields include foundational research such as artificial chromosomes, artificial phages, and the construction of artificial cells based on genetic modification.

Meanwhile, in the green bio-manufacturing field, the adoption of research institutions in major cities of the Bohai Economic Rim such as Tianjin and Beijing is notable. The adopted fields are mostly application-oriented issues directly linked to applications such as the construction of industrial microbial genomes and efficient enzyme production, although some appear to overlap with the synthetic biology project selections.

277 中国生物技术发展中心「合成生物学」: https://www.ncsti.gov.cn/kjdt/tzgg/202111/t20211115_51308.html

278 The evaluation committee for the synthetic Biology project consists of Group 1 “Design and Construction of Special Microbial Chassis Cells” with 7 members including Professor Zhang Ya Ping of Shihezi University (Xinjiang Uygur Autonomous Region) and Group 2 “Synthetic Biosensor Systems for Food Safety Detection” with 7 members including Researcher Chen Yan of the National Center for Food Safety Risk Assessment (国家食品安全风险评估中心). https://www.ncsti.gov.cn/kjdt/tzgg/202106/t20210608_33993.html

279 “Green Bio-Manufacturing” field: https://www.ncsti.gov.cn/kjdt/tzgg/202106/P020210621622063947151.pdf

Table A-4 List of Projects Adopted in China's National Key Research and Development Program: Synthetic Biology and Green Bio-manufacturing

No.	Programs	Projects	Leading Research Institution	Duration (Years)	Budget (10,000 Yuan)
1	Synthetic Biology	Design, construction, and functional research of artificial chromosomes in eukaryotes	Peking University	5	Total of 25 projects: 350 million yuan (about 6.65 billion yen, approximately 14 million yuan (about 266 million yen) per project)
2		Design, synthesis, and functional research of unnatural bases and unnatural cells	Institute of Basic Medical Sciences for Chinese Academy of Sciences	5	
3		Design and construction of microbial foundational cells for special environments	Shanghai Jiao Tong University	5	
4		Rational design and system modification of microalgae-based cells	Henan University	5	
5		Rational design and system modification of microalgae-based cells	Qingdao Institute of Bioenergy and Bioprocess Technology, Chinese Academy of Sciences	5	
6		Construction of nano artificial hybrid biological systems and their application in tumor immunotherapy	Zhejiang University	5	
7		Nano artificial hybrid biological systems for early diagnosis and treatment of pancreatic cancer	East China University of Science and Technology	5	
8		Biosensing system for accurate diagnosis and monitoring of serious diseases such as malignant tumors	Zhejiang Cancer Hospital	5	
9		Research on synthetic biology sensor systems for food safety inspections	Guangdong Institute of Microbiology	5	
10		Efficient treatment system for landfill leachate based on synthetic microbial flora	Guangdong Institute of Microbiology	5	
11		Design and construction of high-energy glucose batteries	Chinese Academy of Sciences, Tianjin Institute of Industrial Biotechnology	5	

12		Combinatorial biosynthesis for constructing artificial products with new skeletons	Huazhong University of Science and Technology	5	
13		Chromosome engineering of special yeast-based cells	Fudan University	5	
14		Synthetic biology research on the fundamental principles of biological pattern formation and artificial control	Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences	5	
15		Design, construction, and application of unnatural photosynthetic autotrophic organisms	Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences	5	
16		Design and synthesis of pathogen tracer compound marker systems	Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences	5	
17		Design and construction of biological carbon chain extension and energy storage cells	Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences	5	
18		Design and synthesis of unnatural artificial phages	Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences	5	
19		Synthesis and application of high-efficiency preparations of bacteriophages targeting Pseudomonas aeruginosa	Third Military Medical University of the Chinese People’s Liberation Army	5	
20		Design and synthesis of genetic circuits for diagnosis and treatment of drug-resistant bacteria	Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences	5	
21		Design of biochemical reactions and construction of efficient biosynthesis systems for new nitrogen-containing molecules	Fudan University	5	

22		Design of biochemical reactions and construction of efficient biosynthesis systems for new nitrogen-containing molecules	Chinese Academy of Sciences, Tianjin Institute of Industrial Biotechnology	5	
23		DNA information preservation in the immune microenvironment of bladder cancer	Shenzhen University	5	
24		Design and mechanism study of tumor environment-targeted immunotherapy targeting T helper cells	Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences	5	
25		Research on novel combination immunotherapy of oncolytic virus bispecific antibodies for “secondary reprogramming of tumor microenvironment”	Sun Yat-sen University	5	
1	Green Bio-manufacturing	Intelligent design and catalytic application of industrial enzymes	Hubei University	3	Budget is declared by request, but in the 2022 call for proposals, a large project budget of 35 million yuan (about 665 million yen) over three years was solicited in the category of “bounty system (揭榜挂帅)”
2		Construction of a general high-efficiency expression system for industrial enzymes	Institute of Animal Sciences, Chinese Academy of Agricultural Sciences	3	
3		Enzyme production and catalyst action in pharmaceutical and food industries	East China University of Science and Technology	3	
4		Molecular design of core enzymes and intelligent manufacturing of enzyme preparations in light industry	Tianjin University of Science and Technology	3	
5		Design principles and methods for efficient microbial cell factories	Shandong University	3	
6		Foundation construction and adaptability optimization in the microbial pharmaceutical industry	Shanghai Jiao Tong University	3	
7		Construction and application of next-generation network models for pathogenic microorganisms and biomanufacturing of important industrial chemicals	Beijing University of Chemical Technology	3	

8		Artificial dislocation technology for industrial pathogenic microorganisms	Tianjin University	3	
9		Modifications to and industrial demonstration of important amino acid industrial pathogenic microbial systems	Jiangnan University	4	
10		Demonstration of core technology and industry for the modification of pathogenic microorganisms in the pharmaceutical ingredient industry.	Zhejiang University of Technology	4	
11		Bioreactors and smart biomanufacturing	East China University of Science and Technology	3	
12		High-efficiency membrane separation technology and integrated equipment for bioethanol production	Nanjing Tech University	3	
13		Key technologies for efficient production and comprehensive utilization of sugars from lignocellulosic biomass	Shanghai Jiao Tong University	3	
14		High-efficiency biomanufacturing technology for artificial meat	Jiangnan University	3	
15		Biomanufacturing technology for products containing natural enzymes	Northwest University	3	
16		Cellulosic ethanol biorefinery and industrial demonstration	South China Agricultural University	4	
17		Green manufacturing and industrial demonstration of complete biosynthetic biological polymers	Nanjing Tech University	4	
18		Efficient green production and industrial demonstration of bio-based polyamide monomers and materials	Institute of Microbiology, Chinese Academy of Sciences	4	
19		Development and industrialization demonstration of new bio-based polyurethane polyols and technology for green manufacturing	Nanjing Tech University	4	

20		Green biomanufacturing and industrial demonstration of chiral chemicals	Chinese Academy of Sciences, Tianjin Institute of Industrial Biotechnology	4	
21		Industrial demonstration of API biomanufacturing for the prevention and management of major diseases	Zhejiang University of Technology	4	
22		Efficient treatment and resource recovery technology demonstration for high-salt organic wastewater	Jiangnan University	4	
23		Creation and catalyst action of industrial enzymes for functional carbohydrates in medicine and food	Tianjin University	3	
24		Molecular design and efficient production of key oxidoreductases for light industry	Institute of Animal Sciences, Chinese Academy of Agricultural Sciences	3	
25		Design principles and operation methods for large DNA fragments of industrial microbial genomes	Tianjin University	3	
26		Adaptation and optimization of industrial foundation for and important drug biosynthesis pathways in filamentous bacteria	Qingdao Institute of Bioenergy and Bioprocess Technology, Chinese Academy of Sciences	3	

Source: National Science and Technology Management Information System's Public Service Platform （国家科技管理信息系統公共服務平台）[280]（As of December 15, 2021）

280 The National Science and Technology Management Information System's public service platform is constructed and operated by the Institute of Scientific and Technical Information of China

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