A Report on Innovation in

Global Life Science Hubs

2024

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Zhongguancun Life Science Park

Zhongguancun Life Science Park, located in the western area of Future Science City in Changping District, Beijing, covers a total area of 7.2 square kilometres. It serves as a critical support platform for Beijing's "Three Cities and One District" International Science and Technology Innovation Centre, an essential part of the technology innovation zone within the Beijing Free Trade Pilot Zone, and a key specialized park in the Zhongguancun National Independent Innovation Demonstration Zone. The park is rapidly advancing its role as a primary hub for high-level talent in Beijing and is positioned as a globally leading "Life Valley". It aims to establish itself as a globally competitive hub for the pharmaceutical and healthcare industries. After years of development, the Life Science Park has become one of the most concentrated areas of innovation resources in China's life sciences sector and a driving force for the development of Beijing's pharmaceutical and healthcare industries.

Nature Research Intelligence

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Executive Summary

Life and health are the eternal themes of human social development and the core goals of a country or city's development. In recent years, the field of life sciences has garnered increasing attention, with continuous breakthroughs in frontier technologies and empowerment driven by cross-disciplinary integration, accelerating advancements in this domain. To provide a comprehensive reference for the innovative development of life science hubs, **Nature Research Intelligence** has compiled *A Report on Innovation in Global Life Science Hubs 2024*. This report leverages cutting-edge data tracking from life sciences publications and global case studies. It objectively evaluates the innovative progress of 22 global life science hubs from the perspectives of scientific talent, international collaboration, and application of research outcomes. Additionally, it provides in-depth analyses of the practices of Boston, Seattle, Paris, Beijing, and Shanghai in advancing innovation within their life science hubs. The report serves as a strategic guide for understanding the historical evolution and future trajectories of innovation in life science hubs.

The global life sciences sector is witnessing intense competition in frontier research and development. Global issues such as population growth, ageing, epidemic diseases, and environmental issues have been fueling the rapid expansion of the market size of the life sciences field. Driven by strong demand, global R&D investment in the field of life sciences has reached $300 billion. In the meantime, developed economies such as the United States, the European Union, the United Kingdom, and Japan, as well as emerging economies like China and India, have intensified their strategic focus and funding for R&D in life sciences. As a result, the scale of research has grown rapidly, leading to a continuous stream of groundbreaking achievements. While North America and Europe exhibit more mature development, Asian countries are progressing at a remarkable pace.

The "intensity," "breadth," and "speed" of innovation have become defining characteristics of global life science hubs today. International innovation hubs such as New York, Tokyo, and Beijing are steadily increasing their investment and output in life sciences. Meanwhile, smaller innovation centres like San Diego, Florence, Lausanne, and Rotterdam have almost exclusively focused on life sciences, driving the development of regional strengths. From the current landscape, it is evident that the world's leading life science hubs are almost all regions where various innovation resources are highly concentrated. Looking at the trends, international collaboration in life sciences is deepening, making the ability to foster exchange and cooperation a critical factor for success. In terms of outcomes, the quality of research in life sciences has significantly improved, with high-impact academic publications and expanded industrial application scenarios continuing to emerge.

Policy support is a key driving force for the development of life science hubs. Globally, government policy support has played a vital role in promoting the development of the life science industry. The successful practice of global life science hubs shows that policies can not only promote the construction of an innovation ecosystem within a hub, but also guide the efficient allocation of innovation resources. China's "14th Five-Year Plan" and local government support for life science hubs also provide critical support for industrial development in terms of policy. Motivated by the policies, the hubs have not only attracted investment and cooperation in international capital and technology, but also facilitated the integration and utilization of domestic innovation resources.

The global life science hubs demonstrate diverse innovative development models. Boston has emerged as a leader in the life sciences field, leveraging its high-level life sciences innovation ecosystem and transforming the globally renowned Route 128, previously famous for electronic information technology, into a global hub for life sciences. Seattle has become a major centre for life sciences development on the U.S. West Coast, relying on its robust healthcare system and cross-regional collaborations. Paris, with its international clinical resources and industry-academia-research partnerships, has become an important hub for life sciences innovation in Europe. Beijing is accelerating breakthroughs in original innovation in life sciences by integrating China's cutting-edge R&D resources. Continuing its legacy of openness, inclusivity, innovation, and diversity, Shanghai is fast-tracking international cooperation in China's life sciences sector. While these hubs differ in organizational forms, they share several key common elements and exhibit inherent connections.

The development of global life science hubs faces both significant challenges and opportunities. On the one hand, issues such as the global capital downturn, technological competition, bioethics, and the alignment of regulations and standards present complex challenges for the growth of life sciences. These issues place higher demands on institutional innovation, government regulation, economic incentives, and legislation in countries worldwide. On the other hand, breakthroughs in frontier life sciences technologies and their applications in other fields bring tremendous opportunities for industrial growth. Emerging technologies like synthetic biology, brain-computer interfaces, ultra-high-resolution imaging, and AI-driven drug discovery, along with "bio plus" production models such as bio plus chemical and bio plus energy approaches, are set to become transformative forces driving paradigm shifts in the life sciences. China's life science hubs are experiencing strong growth, but also facing significant challenges. In recent years, China's life science hubs, represented by innovation hubs in cities such as Beijing and Shanghai, have developed rapidly, demonstrating notable achievements in areas like new drug development, medical device innovation, and modern traditional Chinese medicine. However, intensifying international competition and a shortage of talent are critical issues confronting life science hubs globally.

The new wave of technological revolution, the construction of major scientific infrastructure, and cross-disciplinary innovations driven by related technological advancements are all catalyzing the development of the life sciences field. To seize the critical opportunity window for innovation and development in life sciences, this report provides a multi-dimensional quantitative analysis and case studies on the development paths of global life science hubs. It reveals the innovation strengths of major global hubs and highlights the vast potential for future collaboration. This aims to support governments, enterprises, and research institutions in identifying new breakthroughs and growth opportunities within the global life sciences landscape.

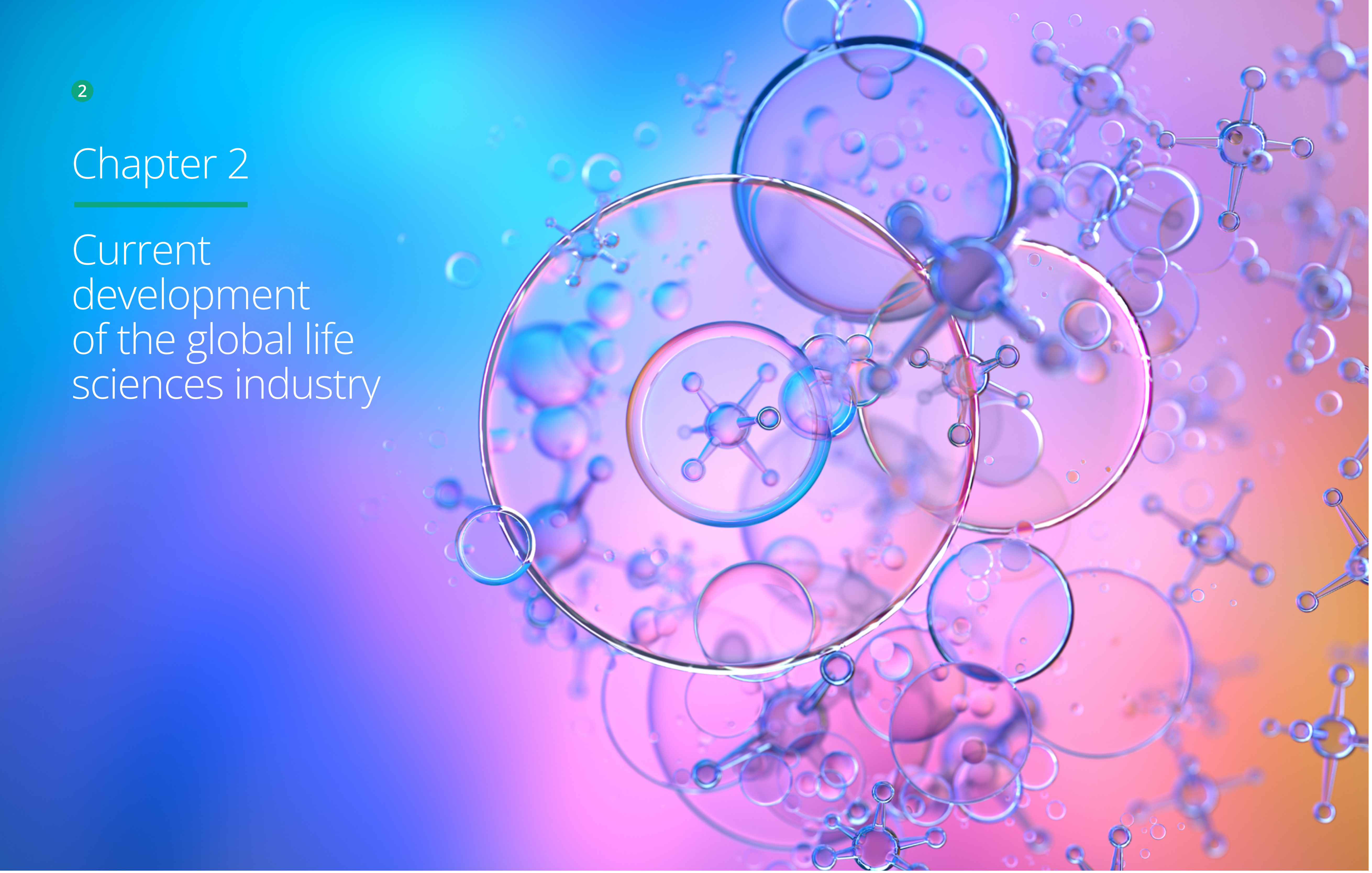
Chapter 1 Introduction

The new wave of technological revolution and industrial transformation is progressing rapidly, with scientific research expanding into the macroscopic scale, delving deeper into the microscopic realm, advancing under extreme conditions, and intensifying cross-disciplinary integration, continuously pushing the boundaries of human knowledge. In recent years, the field of life sciences has experienced accelerated innovation and development, driven by advancements in areas such as synthetic biology, brain-computer interfaces, new drug discovery, bioengineering, cell atlas mapping, precision medicine, and vaccine development. These breakthroughs have enabled humanity to overcome disease challenges and push the limits of human physiology. At the same time, developments in artificial intelligence, biochip technology, optical imaging, nanomaterials, and laser-ray technology are propelling significant innovations at the intersections of life sciences and other fields. These advancements are also accelerating the life sciences ecosystem, spanning the entire chain and lifecycle from fundamental research and experimental development to commercialization[1].

The pursuit of health and longevity, the expansion of physical limits, the eradication of diseases, and the exploration of human-machine coexistence continue to drive the market expansion of the life sciences sector. In recent years, countries worldwide have successively introduced strategic plans and policy frameworks to support innovation and development in life sciences, promoting the collaborative transformation of their domestic life sciences industries amidst the new wave of technological revolution. Additionally, universities, research institutions, and multinational corporations around the globe are intensifying their focus on R&D and talent cultivation in key areas of life sciences, recognizing the sector as the "next growth frontier" after information technology. As a result, the scale of innovation within global life science hubs is rapidly expanding, accompanied by increasingly intense competition.

Globally, developed countries and key regions such as Boston and the San Francisco Bay Area in the United States, Lausanne in Switzerland, London in the UK, Paris in France, and the Tokyo-Kobe area in Japan have demonstrated strong advantages in building innovation hubs in the life sciences sector. These regions continuously drive the integration of global innovation resources, accelerate the attraction and convergence of top talent, and have become the epicentres of life sciences innovation and development today. In this wave of globalization, China's R&D innovation and industrial development in the life sciences sector are also rapidly rising. Life science hubs like Beijing, Shanghai, and Suzhou are gradually becoming integrated into the global innovation cooperation network, contributing "Chinese strength" to the development of the life sciences field[2].

Based on the bibliometric data of Nature Research Intelligence, this report provides insights into the development of scientific and technological talents behind life science literature, the global scientific research cooperation network, and the links between basic research and industrialization in key areas, and showcases the innovative progress in the field of life science. At the same time, the report delves into the development models and main characteristics of life science hubs worldwide. Building on this, it analyzes the opportunities, challenges, and innovation trends in the life sciences sector, aiming to better promote the development of the field, enhance international cooperation, and foster healthy competition.



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Chapter 2

Current development of the global life sciences industry

According to the forecast by World Health Organization (WHO), the proportion of the global population aged 60 and above will double from 12% to 22% between 2015 and 2050[3]. Under the influence of various factors such as population ageing, environmental issues, climate change, global pandemics, and infectious diseases, public health and immunity face increasingly severe potential threats, with rising prevalence of chronic diseases, cancer, and other serious illnesses. The outbreak of the COVID-19 pandemic has once again drawn global attention to life, health, and public health. With technological advancements and strong support from governments worldwide, the scale of the life sciences industry is experiencing strong growth.

2.1 Global life science industry scale

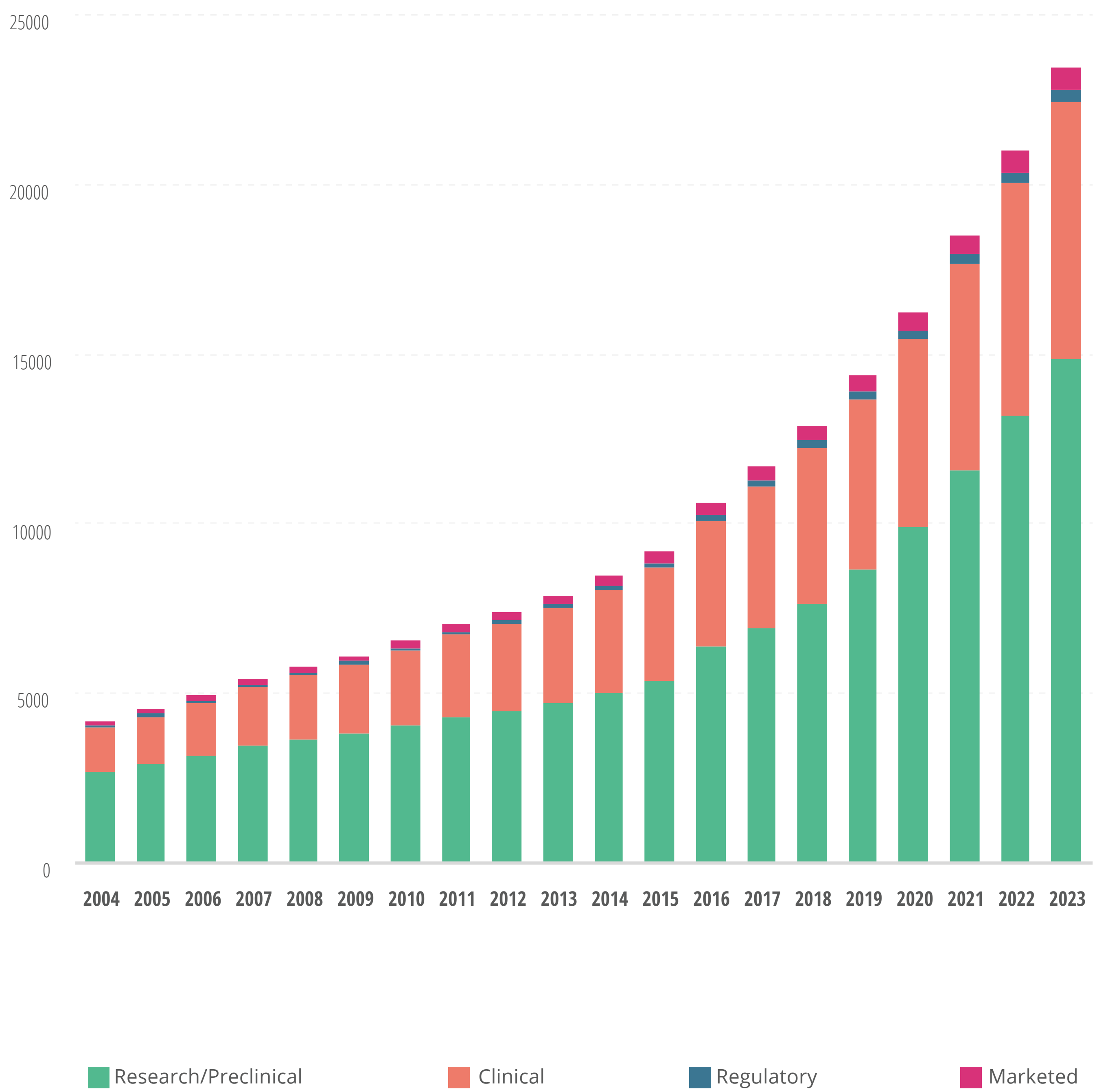
R&D investment in the life sciences industry has increased. In recent years, global R&D investment in the life sciences sector has maintained steady growth. According to the data on the top 2,500 companies' R&D investments, compiled by the European Union's annual "EU Industrial R&D Investment Scoreboard," global R&D funding in life sciences (including pharmaceuticals and biotechnology, healthcare equipment and services) increased from $202.3 billion in 2019 to $284.9 billion in 2022, with a compound annual growth rate (CAGR) of 12.1%, providing continuous momentum for future industry development[4]. According to the AdisInsight database, in 2023, a total of 14,831 drugs were in the R&D/preclinical research stage, 7,586 drugs were in clinical trials, 349 drugs were in regulatory approval, and 646 drugs were in the market promotion phase. Compared to 2004, these numbers were 2,716, 1,277, 67, and 133, respectively. The number of drugs developed and launched globally has been steadily increasing year by year, especially from 2015 to 2023, during which the number of drugs in the R&D/preclinical research phase increased rapidly, with a compound annual growth rate of approximately 13.5%.

The biopharmaceutical industry is growing rapidly. According to the latest IQVIA report, "Global Drug Use Trends 2024 - Outlook to 2028", global drug spending reached $1.6 trillion in 2023. It is expected that the global pharmaceutical market will surpass $2.2 trillion by 2028, with a compound annual growth rate (CAGR) of 6-9% over the next five years. Among them, spending on biopharmaceuticals is projected to increase from $0.5 trillion in 2023 to $0.89 trillion by 2028, with a CAGR of 9.5-12.5%[5], higher than the expected global economic growth rate of 3.2% in 2024[6]. This trend reflects the strong growth momentum of the global life science industry.

The cross-integration of cutting-edge technologies brings new development opportunities. The deep integration of technology and healthcare has brought new growth points to the global biopharmaceutical industry. The new round of technological revolution, including artificial intelligence, genetic technology, and immunotherapy, is driving a tremendous transformation in global life sciences. Many companies are actively exploring how to leverage generative AI, such as OpenAI's ChatGPT and other large language models (LLMs), on top of existing data and AI models. This data-driven approach aims to further improve the drug development process, enhance operational efficiency, reduce research and development costs and failure rates, and accelerate progress. The emergence of genetically engineered drugs and vaccines has provided safer, more effective, and precise methods for treating diseases and preventing infectious diseases, with the development

Figure 1

Global drug development trends (AdisInsight database)



of personalized and precision medicine becoming a new emerging direction for the industry.

2.2 Life science strategies of countries around the world

With the rapid development and application expansion of global life sciences, multidisciplinary cross-integration and symbiosis have promoted disruptive innovation in cutting-edge technologies. The life science industry has shown the potential to promote industrial revolution and structural adjustment, and is expected to fundamentally solve the major problems currently faced by mankind, such as population, food, resources, environment, and energy. It is an effective way to promote sustainable economic and social development. Competition among countries in the field of biotechnology is also intensifying. Since the beginning of the 21st century, major economies in the world have been strategically positioning themselves in the life sciences field, implementing support policies in areas such as top-level design, technology research and development investment, talent cultivation, and service back-up.

The United States has positioned biotechnology and biopharmaceuticals as a national strategy. In 2023, it released the "U.S. Biotechnology and Biomanufacturing Strategic Vision," which covers five key areas: climate, food and agriculture, supply chains, global health, and genetic biotechnology, aiming to promote the development of biotechnology and biomanufacturing in the U.S[7]. On March 22, 2024, the White House announced the establishment of the National Bioeconomy Council to foster public-private sector collaboration in biotechnology and biomanufacturing[8]. At the same time, the United States continues to strengthen biotechnology research, encourage invention and innovation, and promote biotechnology transfer by studying and formulating corresponding laws and regulations, fiscal budgets, management systems, and tax policies.

The European Union will strongly support the biotechnology and biomanufacturing industries. In March 2024, the European Commission published the communication "Building the future with nature: Boosting Biotechnology and Biomanufacturing in the EU". This initiative aims to promote the development of biotechnology and biomanufacturing in the EU through a series of targeted actions, including utilizing research outcomes to foster innovation, stimulating market demand, streamlining regulatory pathways, encouraging public and private investment, enhancing biotechnology-related skills, updating standards, leveraging regional and sectoral synergies, and fostering international cooperation. These measures are designed to address challenges such as imperfect market transition mechanisms, complex regulatory environments, limited financing channels, and insufficient talent reserves[9].

The UK government established the "Biotechnology Coordinating and Advisory Committee" as early as 1981. In June 2021, the UK government announced the formation of the Office for Science and Technology Strategy (OSTS), aimed at developing, nurturing, and leveraging the UK's scientific capabilities to deliver strategic advantages and benefits to society. Health and life sciences, as one of the two key areas, have received focused attention and increased investment. In the Autumn Statement 2023, a series of measures and investments were introduced, including £520 million (approximately $650 million) allocated for life sciences funding, research and development tax credits, and a clinical trials accelerator programme[10].

Japan formulated the strategy of "building a nation based on bioindustry" in the early 21st century and issued the "Biotechnology Strategy Outline" in 2002 to support the development of life science and technology. In June 2024, Japan established the latest version of its "Bioeconomy Strategy," which aims to leverage Japan's strengths to create a world-leading bioeconomy society. The market is divided into five major areas: 1) Biomanufacturing and bio-derived products, 2) Sustainable primary production systems, 3) Large timber buildings and smart forestry, 4) Biopharmaceuticals, regenerative medicine, cell therapy, and gene therapy-related industries, 5) Lifestyle improvement, healthcare, and digital health. The strategy sets a goal to expand the market size of Japanese companies in these areas to more than 100 trillion yen by 2030, both domestically and internationally[11].

In recent years, **the Chinese government** has also increased its support for the biomedical sector. According to data from the National Bureau of Statistics of China, China's fixed asset investment in the pharmaceutical manufacturing industry increased by 14.8% year-on-year in 2022, significantly higher than the average growth rate of other manufacturing sectors[12]. Additionally, China has implemented a series of policies to drive the development of the life sciences industry. For example, the "14th Five-Year Plan" explicitly outlines the need to integrate biotechnologies and information technologies, accelerate the development of biopharmaceuticals, biobreeding, biomaterials, and bioenergy, and focus on advancing frontier fields such as brain science, brain-like research, genetics, biotechnology, clinical medicine, and health. The plan also aims to streamline approval processes for innovative drugs, vaccines, and medical devices, providing comprehensive health services across the lifespan[13]. The 20th National Congress report emphasized the importance of "promoting the construction of a Healthy China" and prioritizing people's health in development strategies, with policies aimed at promoting health. In September 2024, the National Medical Products Administration announced plans to further accelerate the review and approval of urgently needed innovative drugs and medical devices. Pilot programmes in cities like Beijing and Shanghai will reduce the clinical trial review time for innovative drugs from 60 working days to 30 working days.

In 2024, **the Indian government** approved the "Biotechnology Research Innovation and Entrepreneurship Development" (Bio-RIDE) programme, aimed at promoting the growth of the country's biotechnology industry. The programme consolidates two existing initiatives from the Department of Biotechnology (DBT) and introduces the fields of biomanufacturing and biofoundries. With a total budget of 919.7 billion rupees, the Bio-RIDE programme is set to be implemented from 2021 to 2026. The core objectives of the program include fostering biotech entrepreneurship, promoting innovation, strengthening industry-academia collaborations, supporting sustainable biomanufacturing, attracting external research funding, and developing talent. The program will provide seed funding, incubation services, and expert guidance to biotech startups, while also funding research in cutting-edge fields such as synthetic biology, biopharmaceuticals, bioenergy, and bioplastics[14].

2.3 Geographical distribution of life science industry

With the guidance of policies, a large influx of capital, enterprises, talent, labour, and knowledge has gathered, resulting in the integrated development of the global life sciences industry. The direction of cutting-edge technologies has become increasingly diversified, making it a crucial engine driving global economic growth. From the perspective of global life sciences industry hubs, Europe and North America remain the leaders in the development of the global industry, with advanced biopharmaceutical and healthcare sectors. The hubs demonstrate the following distribution patterns:

North America: The North American market holds a significant position in the global life sciences industry, with advanced medical facilities, strong R&D capabilities, and a large number of life sciences companies. The United States, as the leader of the global life sciences industry, has a biopharmaceutical sector that accounts for approximately 17.36% of its GDP[15], leading the world in both R&D strength and industrial development. U.S. companies dominate the global biopharmaceutical market, holding a majority of global biopharmaceutical patents, with major companies such as Merck, Johnson & Johnson, Roche, and Novartis being key producers. U.S. universities also perform exceptionally well in the field of biosciences, with more than half of the top 200 universities in the QS World University Rankings for biosciences located in the U.S. Furthermore, cities like Boston and Seattle in the U.S. have become renowned global life sciences industry hubs, housing numerous world-leading research institutions and companies.

Europe: Europe is also a major centre for the life sciences industry. Switzerland, the United Kingdom, and France are the leading countries at the forefront of biopharmaceutical technology R&D and commercialization. Lausanne/Geneva in Switzerland, London in the UK, and Paris in France have developed into the most representative life sciences industry hubs in Europe, housing global-leading pharmaceutical companies such as Novartis, Roche, and AstraZeneca. These hubs have formed highly concentrated biopharmaceutical innovation ecosystems. London, with its top universities like University College London (UCL) and Imperial College London, along with multinational pharmaceutical companies such as AstraZeneca and GlaxoSmithKline, has become one of the core hubs for global biopharmaceutical R&D.

Asia-Pacific: This region is one of the fastest-growing areas in the global life sciences industry. Market demand in this region is growing rapidly and is expected to maintain a high growth rate in the coming years. Life sciences industry hubs in Asia are developing rapidly, with China, Japan, and Singapore standing out. In China, cities like Beijing, Shanghai, and Suzhou have become emerging forces on the global innovation map by vigorously developing life sciences industry hubs, achieving significant progress in biotechnology and pharmaceutical R&D. Japan's Tokyo-Kobe medical industry hub, supported by unique policy backing and advanced technological capabilities, has quickly risen to become a leader in Asia's life sciences industry. Singapore, through government-led initiatives such as the establishment of the Research, Innovation and Enterprise Council and inviting top scientists to provide strategic advice, has also become a model for highly concentrated development.

Although **the Middle East and Africa** account for a relatively small share of the global life sciences industry, these regions, particularly Saudi Arabia and South Africa, are gradually becoming important markets. This trend is closely linked to the increasing government investments in healthcare and biotechnology research.

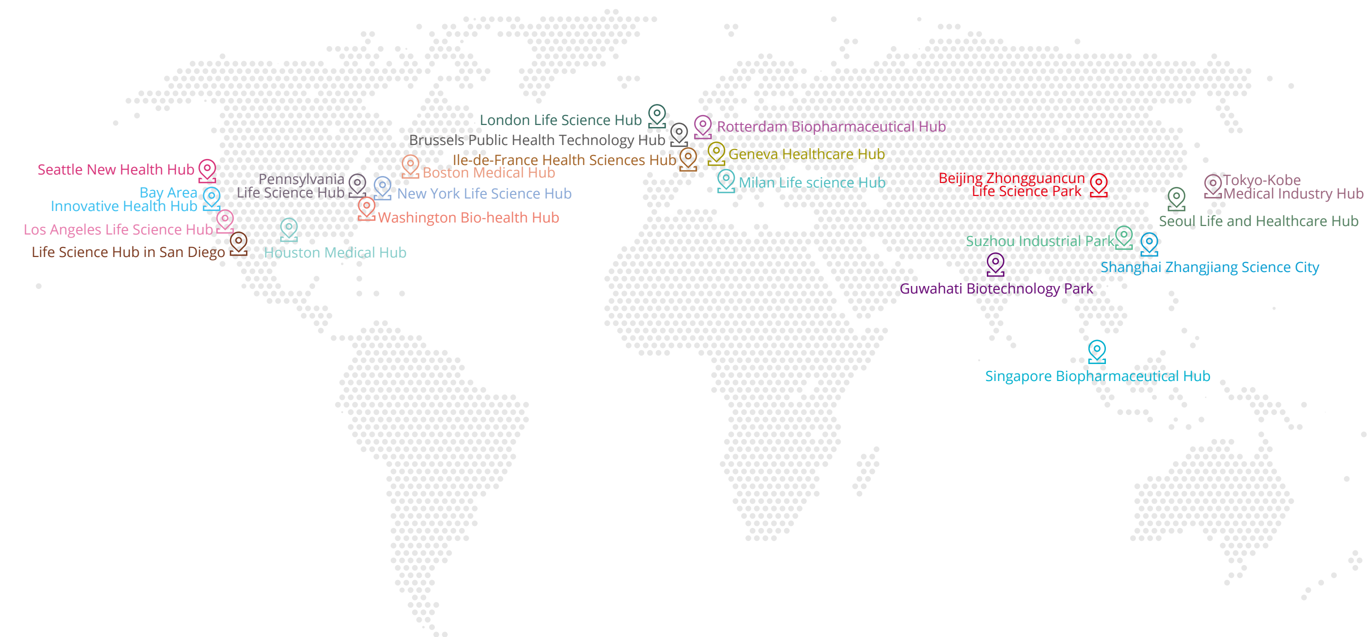
To further understand the development status and future trends of global life science hubs, this report will provide a detailed analysis of representative life science hubs worldwide. Through research on life science hubs from multiple countries and regions, 22 hubs with notable representation in research, talent, industrial chain maturity, and technology commercialization capabilities have been selected. These hubs include the Bay Area life and health hub, Seattle new health Hub, and Boston pharmaceutical hub in the United States, as well as the Geneva life and health industry hub, London Life science hub, and Milan life science hub in Europe, and the Beijing Zhongguancun Life Science Park, Shanghai Zhangjiang Science City, and Suzhou Industrial Park in China, among other notable life science hubs.

2.4 Summary

Globally, the life science industry is developing strongly, the market size is expanding steadily, and the growth rate far exceeds the overall economic development level. Countries are actively positioning themselves with a variety of strategic initiatives, launching medium- and long-term industry plans, establishing specialized organizations, developing roadmaps for specific sectors, encouraging technological innovation, and implementing supporting laws, regulations, and policies to promote the development of the life sciences industry. From the current spatial distribution, due to the concentration of various resources, market demand, and policy guidance, diversified industrial hubs have formed in different regions. Each region has developed its own unique model, with Western countries, particularly in Europe and North America, holding a clear advantage, making them key players in the development of the life sciences industry.

Figure 2

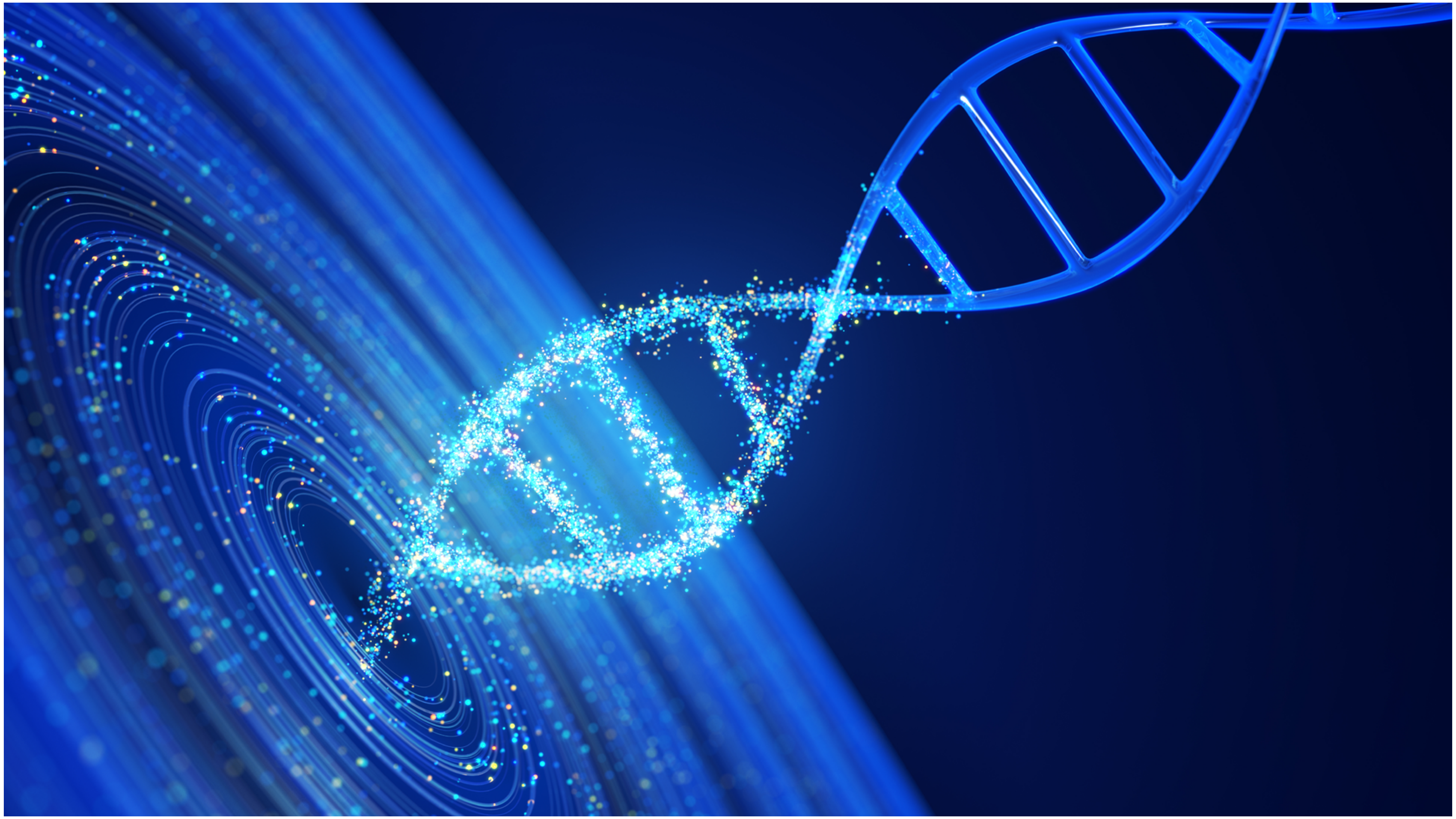
Typical life science hubs around the world



Hub	Geographic location	Country
Bay Area Innovative Health Hub	San Francisco-San Jose	United States
Seattle New Health Hub	Seattle-Tacoma-Bellevue	United States
Houston Medical Hub	Houston	United States
Boston Medical Hub	Boston	United States
Beijing Zhongguancun Life Science Park	Beijing	China
Shanghai Zhangjiang Science City	Shanghai	China
Suzhou Industrial Park	Suzhou	China
Life Science Hub in San Diego	San Diego	United States
New York Life Science Hub	New York	United States
Washington Bio-health Hub	Baltimore-Washington	United States
Los Angeles Life Science Hub	Los Angeles-Long Beach-Anaheim	United States
Pennsylvania Life Science Hub	Philadelphia	United States
London Life Science Hub	London	United Kingdom
Ile-de-France Health Sciences Hub	Paris	France
Rotterdam Biopharmaceutical Hub	Rotterdam	Netherlands
Milan Life science Hub	Milan	Italy
Geneva Healthcare Hub	Lausanne & Geneva	Switzerland
Brussels Public Health Technology Hub	Brussels	Belgium
Singapore Biopharmaceutical Hub	Singapore	Singapore
Tokyo-Kobe Medical Industry Hub	Tokyo & Kyoto-Osaka-Kobe	Japan
Seoul Life and Healthcare Hub	Seoul	South Korea
Guwahati Biotechnology Park	Central National Capital Region Delhi	India

Chapter 3

Research on global life science hubs based on science and technology data



The clustered development of the life sciences industry in a region creates a complex ecosystem where various elements interact and evolve together, fostering greater efficiency and speed in innovation. This chapter, based on scientific literature data from Natural Research Intelligence, explores the performance of key global life science hubs in recent years. It examines aspects such as talent, research capabilities, international cooperation, and the commercialization of research outcomes. The chapter analyzes the distribution characteristics, growth trends, and key factors driving innovation in global life science hubs, creating a dynamic landscape of the global life science hub capabilities.

Considering that most collaborations often occur within the same region, and innovation activities within a hub are not confined to a specific institution or geographic division, the data in this chapter is based on the metropolitan areas where these hubs are located.

3.1 Talent gathering and diversity

Talent is the cornerstone of innovation and development. Major global life science hubs are often located in economically developed cities, attracting researchers, technical experts, entrepreneurs, and professionals in finance and law. In recent years, governments worldwide have been improving and upgrading local education and research support systems, leading the cultivation and attraction of high-level scientific talent, thereby enhancing their technological research and development capabilities. Due to the broad scope of the life sciences industry, the scientific talent involved comes not only from biology and medicine but also requires interdisciplinary collaboration with experts from fields like physics, chemistry, computer science, and engineering, especially in cross-disciplinary areas such as bioinformatics, gene editing, and medical AI.

For example, the life science hub in the San Francisco Bay Area is one of the most vibrant regions for life science innovation globally. The Bay Area is home to prestigious institutions such as the University of California, San Francisco (UCSF), Stanford, and Berkeley, and it also hosts a large number of life science companies, venture capitalists, and incubators. Similarly, Beijing's Zhongguancun Life Science Park is located near China's top universities and research institutions, such as Peking University, Tsinghua University, and the Chinese Academy of Sciences. Additionally, the

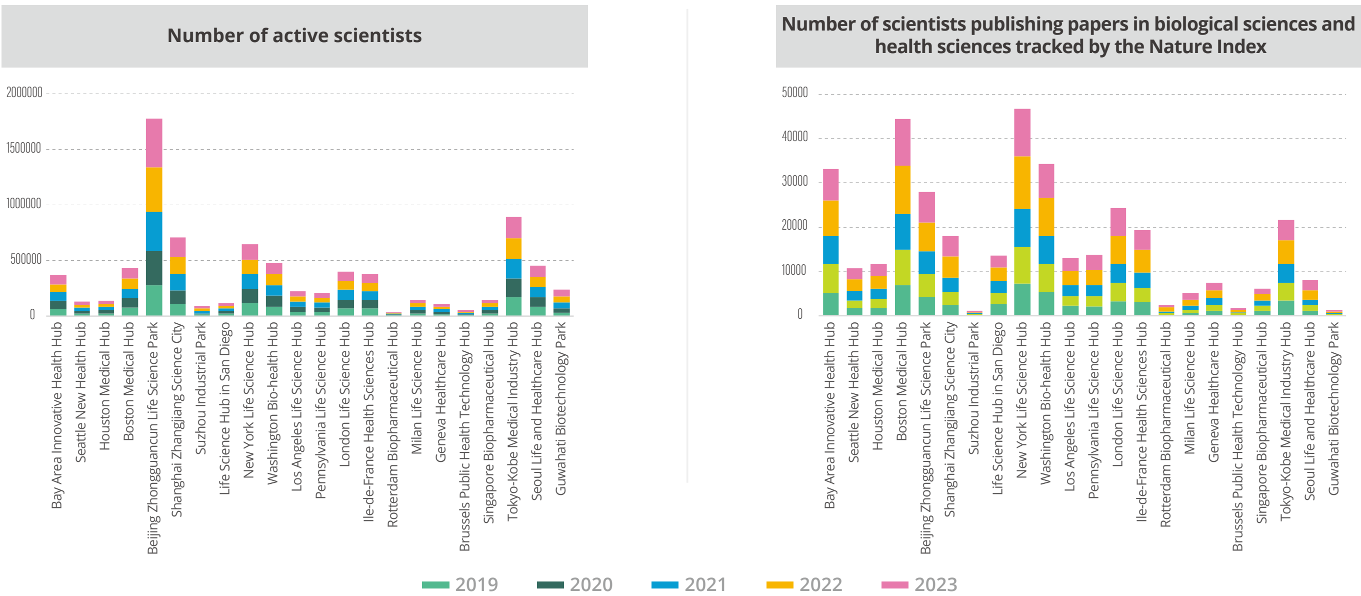
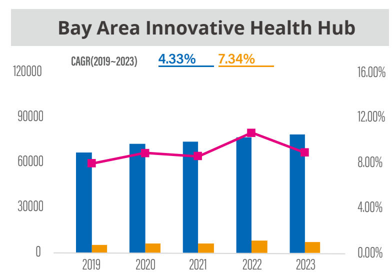
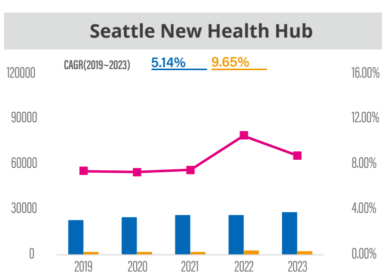


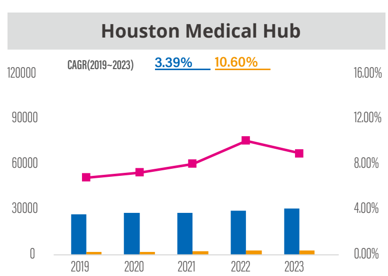
Figure 3

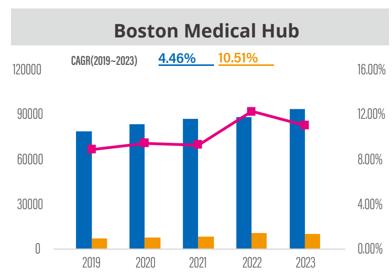
Trends in the number of active researchers and high-level researchers in global life science hubs (2019-2023)

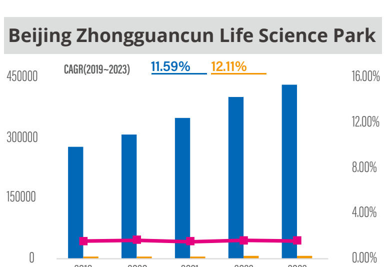
Number of active scientists
Number of scientists publishing papers in biological sciences and health sciences tracked by the Nature Index
Percentage of scientists publishing papers in biological sciences and health sciences tracked by the Nature Index

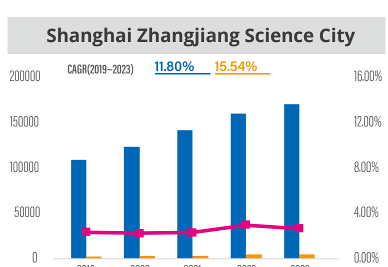


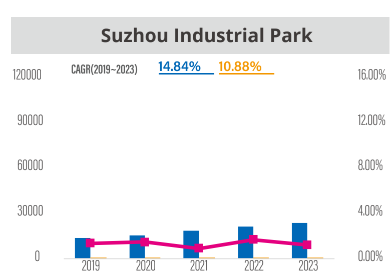












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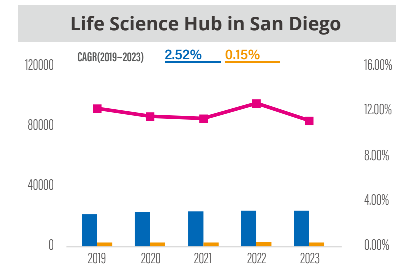
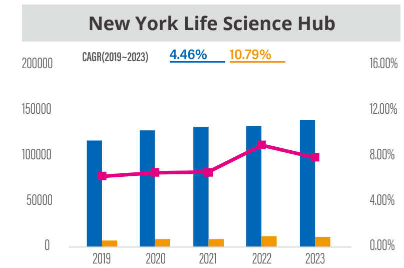
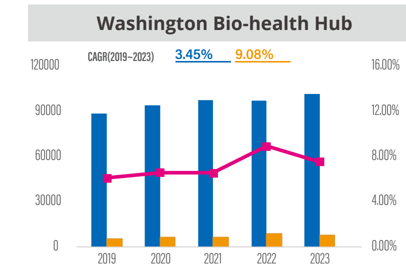
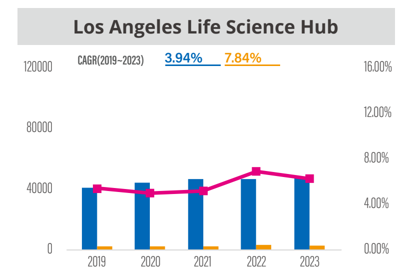
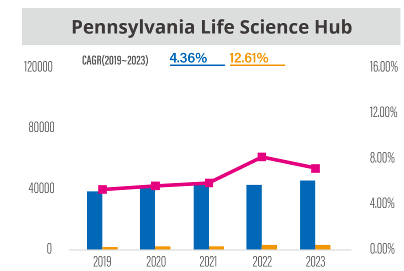
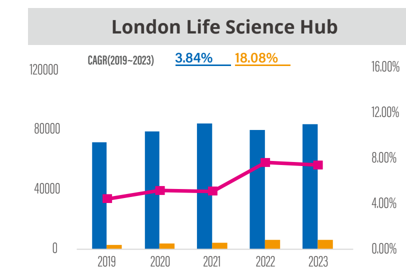


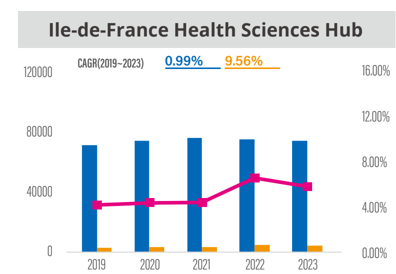


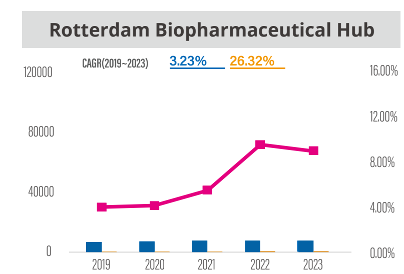


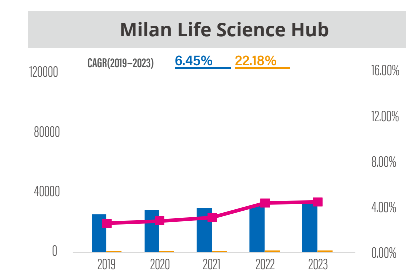


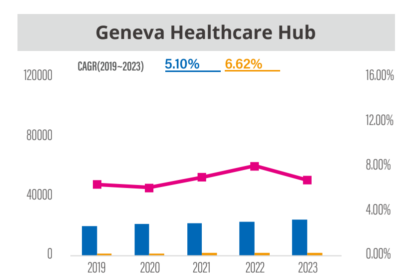


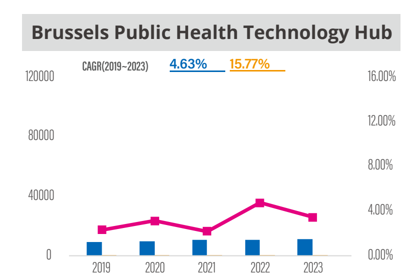


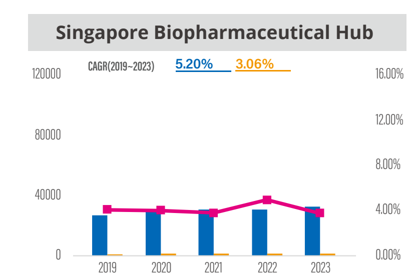


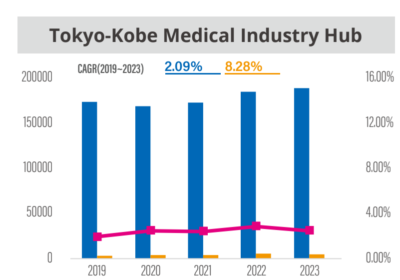


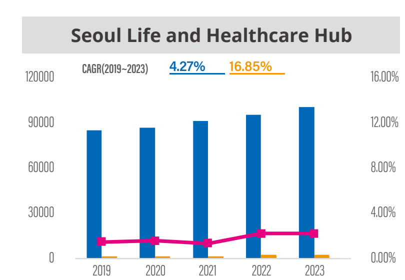


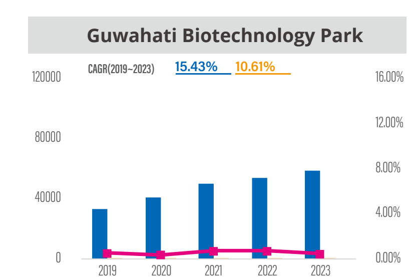












area attracts numerous financial and investment institutions, drawing top talent from around the world.

Beijing is leading in the size of the reserachers pool. Beijing has the largest number of research personnel among global life science hubs. In 2023, the active research personnel in Beijing exceeded 430,000, far surpassing Tokyo at approximately 190,000, Shanghai at around 170,000, New York at about 140,000, Washington's biohealth hub and Seoul's life health industry hub at around 100,000. Hubs with 50,000 to 100,000 research personnel include the Bay Area, Boston, London, Paris, and Guwahati in Delhi. Hubs with fewer than 50,000 include Seattle, Houston, Suzhou, San Diego, Los Angeles, Philadelphia, Milan, Switzerland, Singapore, Rotterdam's biopharma hub, and Brussels' public health tech hub, each with about 10,000 research personnel. Although some well-known hubs, such as Boston, Seattle, and London, do not have the highest number of active researchers, their technology talent is highly concentrated due to their population density. Furthermore, as most of them are famous international cities that attract top talent from around the world, these cities benefit from a diverse and highly skilled talent pool.

East Asia is the fastest-growing region in terms of the number of research personnel globally. Beijing, with the largest base, maintained a compound annual growth rate (CAGR) of 11.59% from 2019 to 2023. Shanghai's CAGR was 11.80%, closely following Beijing. Suzhou and Delhi, with smaller bases, both maintained a CAGR of around 15%. In contrast, the number of active researchers in U.S. life science hubs has been relatively stable, with a CAGR typically ranging from 3% to 5%. Similarly, European life science hubs exhibit a similar growth trend, generally within the 3%-5% range. Italy's hubs showed a relatively faster growth, with a CAGR of 6.45%, Switzerland at 5.1%, and Paris, home to the Île-de-France Health Science Hub, saw stable levels of active research personnel. The number of scientists in European and U.S. hubs is often influenced by immigration policies, causing fluctuations. The rise in active researchers in hubs such as Beijing, Shanghai, and Milan is closely linked to the rapid development of these regions in recent years.

High-level researchers in the life sciences are largely based in the United States. The Nature Index monitors groundbreaking research published in top-tier journals and further analyses the number of researchers who contributed to these publications. Between 2019 and 2023, the number of researchers publishing in top journals fluctuated annually across various hubs, rather than showing a consistent increase or decrease, reflecting the intense competition in cutting-edge science. Calculating the compound annual growth rate (CAGR) for the past five years (2019–2023), most hubs experienced a CAGR of over 7% for high-level researchers. For example, Suzhou's CAGR was 10.88%, while San Diego remained relatively stable. Particularly notable were the European and South Korean regions: the Rotterdam Biopharmaceutical Industry Hub in Europe had a CAGR of 26.32%, Milan's Life science hub had a CAGR of 22.18%, and Seoul's Life and Health Industry Hub in South Korea achieved a CAGR of 16.85%. This highlights the ability of life science hubs to attract and cultivate high-level researchers, who, in turn, drive innovation within the hubs.

Hubs with a long history and smaller, highly concentrated hubs tend to have a higher proportion of high-level researchers in the life sciences field. By analysing the proportion of high-level researchers among all active researchers in various hubs, it is evident that well-established, highly concentrated small-to-medium-sized tech innovation hubs, such as Boston and San Diego, have more than 10% high-level researchers among their active researchers in life sciences. The Bay Area, Seattle, and Houston have over 8%, while New York is around 7%. The highest in Europe is Rotterdam, with a proportion exceeding 9%. Other European hubs and Asian hubs like Tokyo and Seoul typically fall within the 2%-4% range. The high proportion of top-tier researchers in these hubs reflects their advanced capabilities in attracting talent, fostering researchers, and maintaining robust research infrastructures. This forms the competitive advantage of these regions in the life sciences field. In comparison, hubs with a larger number of researchers, such as Beijing, Shanghai, Suzhou, and Delhi, have only about 1% of their active researchers as high-level life scientists, indicating there is still some gap relative to the world's leading life science hubs.

Attracting and nurturing high-level talent is key to the future competitiveness of hubs. Overall, traditional, well-known hubs such as the San Francisco Bay Area, New York, Seattle, and Tokyo maintain a stable number of research personnel, with compound annual growth rates typically under 5%. In contrast, hubs in Asia, particularly Beijing, have seen rapid growth in the number of research personnel, with Beijing maintaining a compound annual growth rate of over 10% despite already having the highest number of active researchers globally. This demonstrates the effectiveness of local economic development, infrastructure, and government policies in attracting talent. The international mobility of talent plays a significant role as well. Cities like Boston, San Francisco, London, Beijing, and Shanghai, with their international atmosphere and open policies, have attracted a large pool of highly skilled researchers. For example, world-renowned scientists such as Xiaoliang Xie have established labs in Beijing's Zhongguancun Life Science Park, alongside others like Xiaodong Wang and Feng Shao, further attracting numerous researchers. This fosters international collaborative innovation. These talents are the core driving force behind the innovation and rapid development of their respective hubs. The support and nurturing of talent by these hubs has fueled the growth of a skilled talent pool, enhancing the innovation dynamism of the entire hub. Distinguished scientists such as Xiaoliang Xie, Xiaodong Wang, Yi Rao, Feng Shao, and Minmin Luo have joined institutions like the Changping Lab in Zhongguancun Life Science Park, the Beijing Institute of Life Sciences, and the Beijing Brain Science and Brain-Like Research Institute, further enhancing international collaboration and driving innovation.

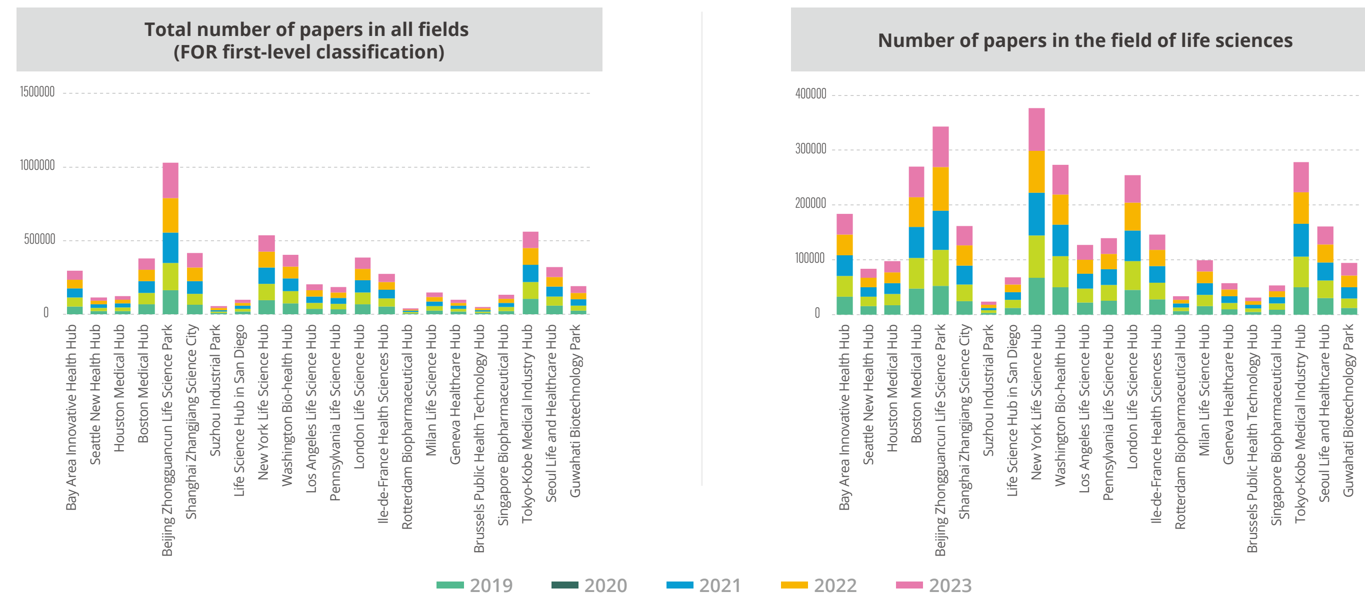
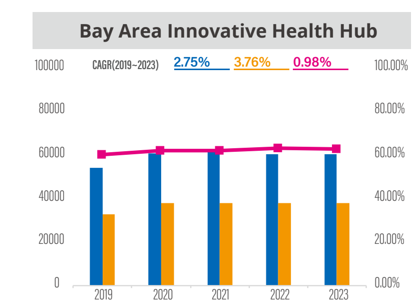
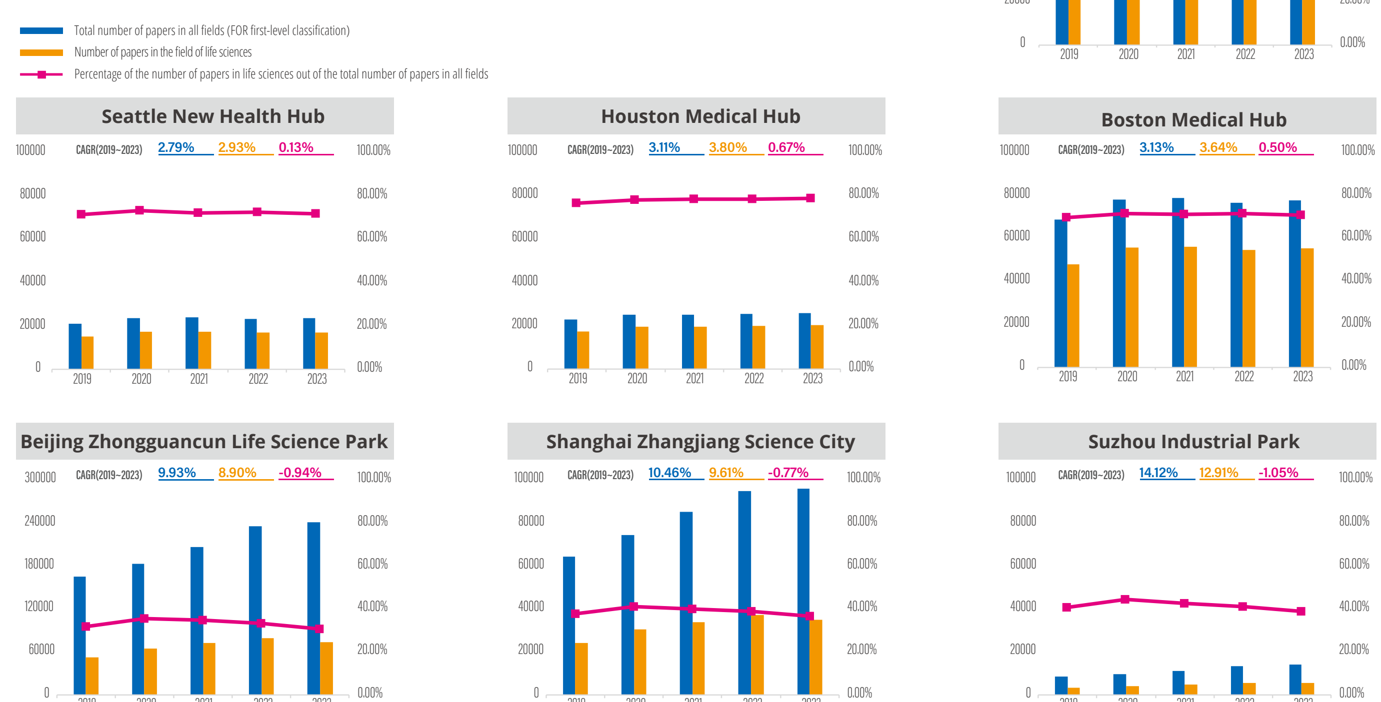


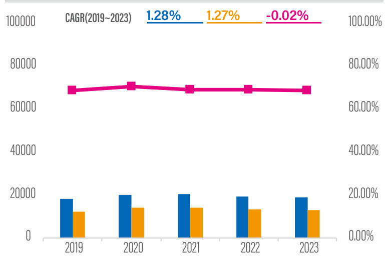
Figure 4

Trends in publication volume in all fields of the global life science hub and in the life science field (2019-2023)

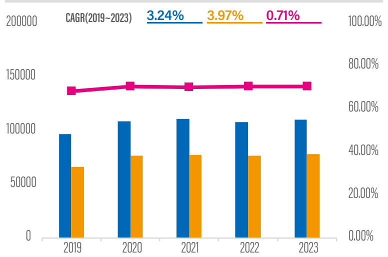




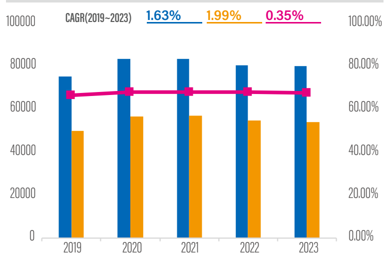
Life Science Hub in San Diego



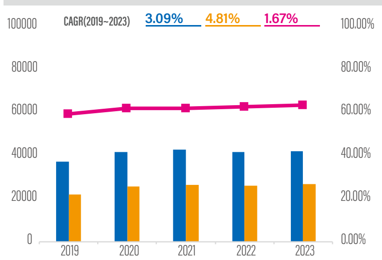
New York Life Science Hub



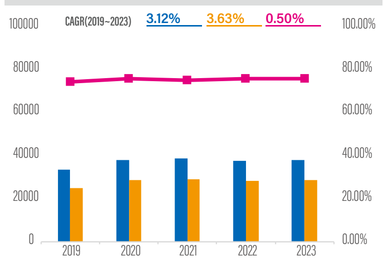
Washington Bio-health Hub



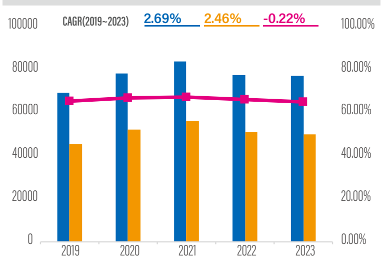
Los Angeles Life Science Hub



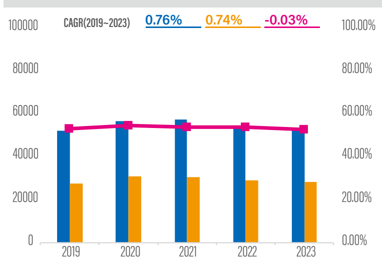
Pennsylvania Life Science Hub



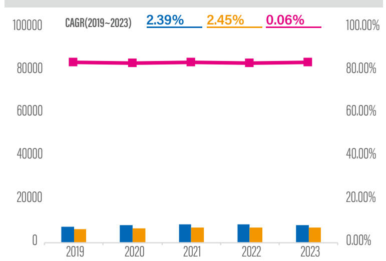
London Life Science Hub



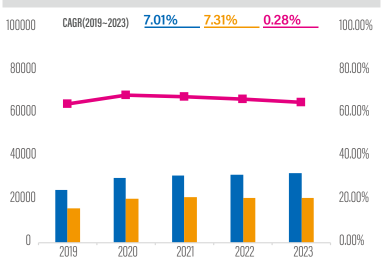
Ile-de-France Health Sciences Hub



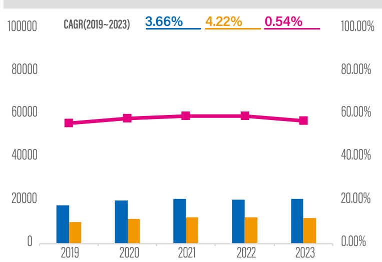
Rotterdam Biopharmaceutical Hub



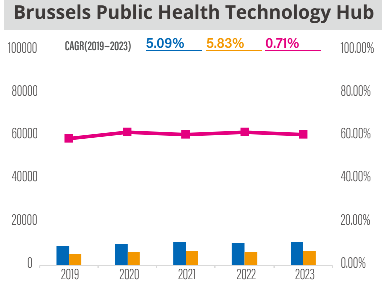
Milan Life Science Hub



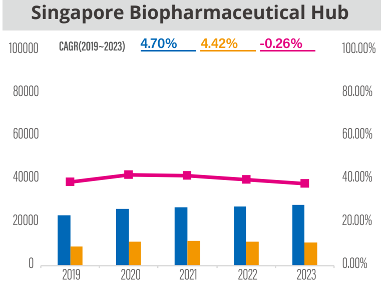
Geneva Healthcare Hub



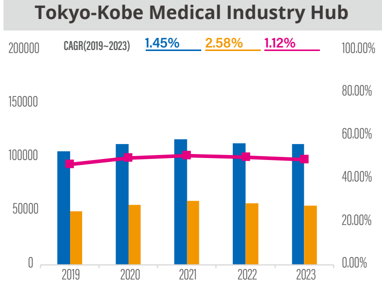
Brussels Public Health Technology Hub



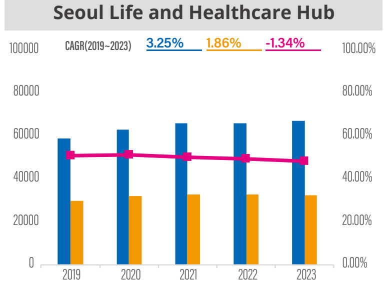
Singapore Biopharmaceutical Hub



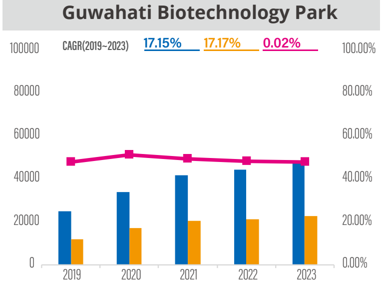
Tokyo-Kobe Medical Industry Hub



Seoul Life and Healthcare Hub



Guwahati Biotechnology Park



3.2 Basic scientific research breakthroughs and international cooperation

Regions that leverage demographic dividends tend to have large and rapidly growing basic research outputs. The foundational research capabilities of global life science hubs drive their overall innovation activity. The research capacity of the cities where these hubs are located has continued to improve, with one of the key metrics being the number of published papers, which has shown an upward trend from 2019 to 2023. In absolute terms, Beijing has the highest number of papers, averaging over 200,000 annually. Other hubs, such as those in New York and Tokyo, also around 100,000 papers annually. In terms of growth, cities like Delhi, Suzhou, Shanghai, and Beijing have experienced the fastest increases in scientific output, with compound annual growth rates approaching or exceeding 10%. Meanwhile, established life science hubs like the San Francisco Bay Area, Seattle, Houston, and New York have seen more stable levels of research output.

The United States and Europe have deep historical foundations in the field of life sciences. The proportion of life sciences-related papers in the total number of publications indicates that the majority of historically established hubs, such as those in the US and Europe, account for over 60% of the total publications in life sciences. In the Rotterdam biomedical industry hub, this proportion even reaches 83%. This highlights that, with prestigious life science innovation institutions such as Harvard University, Dana-Farber Cancer Institute, and Memorial Sloan Kettering Cancer Center, life science hubs benefit from a wealth of research accumulation, making their advantages more prominent and their field concentration higher. In rapidly developing hubs like Beijing, Shanghai, Suzhou, and Delhi, the concentration of life sciences research is relatively lower. Their strength lies in the rapid development of all disciplines, with cross-disciplinary integration becoming a significant development opportunity.

Harvard, MIT, and other universities lead the world in high-quality life science output. Breakthroughs in basic research often drive industry innovation. Regarding high-quality research outcomes, cities hosting major hubs like New York, Boston, Washington, the San Francisco Bay Area, Beijing, San Diego, London, Paris, and Tokyo have a significant number of high-quality results in relevant fields, especially in New York with Columbia University and Yale, and in Boston with Harvard and MIT, where the quantity of high-quality outcomes far surpasses other regions. In terms of growth rate, all hubs, except for San Diego, show a rapid upward trend. Even one of the largest hubs, Boston, maintains a compound annual growth rate (CAGR) of 10%, with Beijing, Shanghai, and Suzhou also showing around 10% growth, indicating that global life sciences have been developing rapidly in recent years. Milan, Rotterdam, and Brussels have a CAGR of around 20%, indicating that high-quality life science research is developing quickly in these hubs. From the perspective of high-quality research as a percentage of total life science publications, San Diego, the Bay Area, Boston, and Seattle each have around 4%, suggesting that these regions stand out for their high-quality research. The development of life science hubs is closely tied to the scientific strength of the local life science research community, and high-level research further drives the growth of the hub.

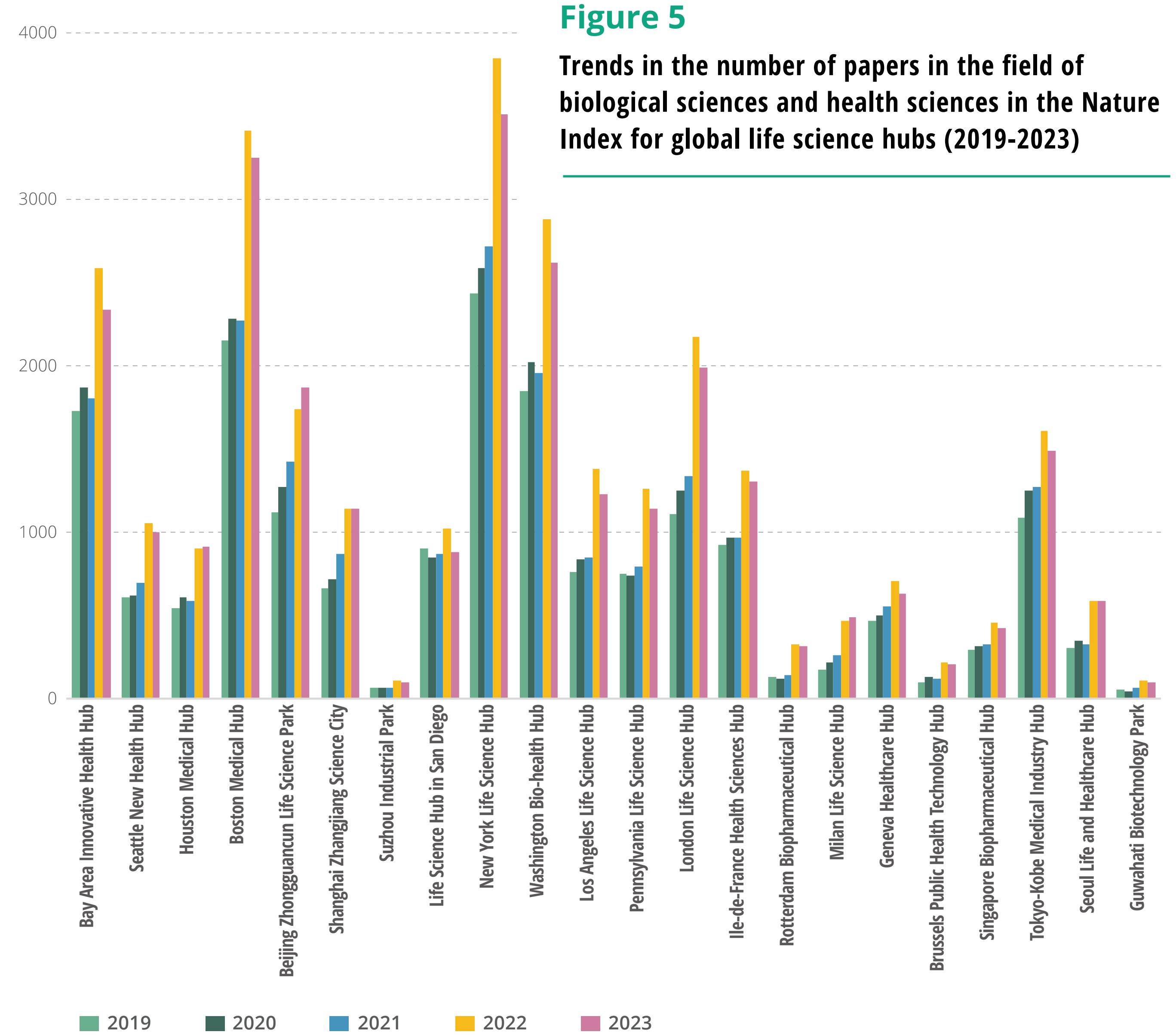
Europe's international cooperation is more open and diverse. International collaboration has become a key factor in improving research levels. Between 2019 and 2023, the number of international collaborative papers in high-quality articles continued to grow across global life science hubs. New York, Boston, and London had far more international cooperation papers than other hubs, with international platforms serving as key hubs for cooperation. There are 13 hubs with a compound annual growth rate (CAGR) of over 10%, mostly concentrated in Europe and North America, with Milan having the highest CAGR of 27%. Beijing and Shanghai's growth rates are around 7%, while Suzhou and San Diego have slower growth. This reflects differences in the expansion speed of hubs within the international cooperation network. In terms of the proportion of international collaborative papers to total papers, European hubs generally have an international cooperation share exceeding 80%, with Brussels' public health and technology hub reaching 91%. This highlights the accelerated flow of innovation resources such as talent, knowledge, technology, and data in Europe, positioning it as an important bridge for global international cooperation.

"High quality" and "internationalization" have become the key trends in the development of scientific research in the life sciences. Comparing the compound annual growth rate (CAGR) of three types of papers — total life science papers, high-quality papers in biological and health sciences indexed by Nature Index, and high-quality papers with international collaboration indexed by Nature Index — it is clear that the CAGR of high-quality papers and high-quality papers with international collaboration exceeds 10%, which is 5% higher than the overall average CAGR for life science papers. This highlights the significant role that high-quality outcomes and international collaboration play in advancing life science research and suggests that these factors will become key drivers of future life science development. These key life science hubs are typically located in well-developed cities in terms of technology, economy, and society, where large numbers of universities, research institutions, and key enterprises are concentrated. These hubs tend to have higher levels of internationalization, and researchers have more opportunities for international exchange and collaboration. In contrast, high-level research in Beijing, Shanghai, and Suzhou tends to be more localized, with the CAGR of high-quality international collaborative papers in these cities not reaching the global average, all falling below 10%, and also lower than the growth rates of total life science papers and high-quality papers.

The 22 key life science hubs around the world are generally characterized by active scientific research and abundant research output, maintaining a rapid growth momentum over the past five years. In hubs with a deep scientific and cultural foundation, research in

Figure 5

Trends in the number of papers in the field of biological sciences and health sciences in the Nature Index for global life science hubs (2019-2023)



life sciences is more concentrated and dominates the field. In emerging hubs, the range of research areas is more diverse. The output of high-quality research results is growing more rapidly, and international collaboration further promotes the development of high-quality scientific achievements. Active research activities, along with high-quality and breakthrough research results, are driving the innovation activities and technological advancements in life science hubs.

Research activity in cutting-edge fields varies by focus area. Synthetic biology, brain science, phenomics, computational biology, and gene and cell therapies are some of the forefront areas in life sciences, with groundbreaking results emerging frequently. The volume of papers in these fields has grown rapidly over the past decade, with computational biology seeing the most rapid growth, with a compound annual growth rate of 50.8% over the past 10 years. Brain science has attracted the most researchers, with more than 670,000 papers published in 2023. Comparing research activity across the 22 hubs in these frontier fields, Beijing stands out for its high activity in all five fields, leading the world in the number of papers published. London, Boston, and New York are particularly focused on computational biology and gene and cell therapies, while Shanghai concentrates on gene and cell therapies. The distribution of research activity is influenced by the current hotspots in life sciences, the interests of local researchers, the business focus of emerging enterprises, the priorities of investment and financing institutions, and the strategic planning of local governments and hub management agencies.

Figure 6

Trends in international collaboration on high-level papers in global life science hubs (2019-2023)

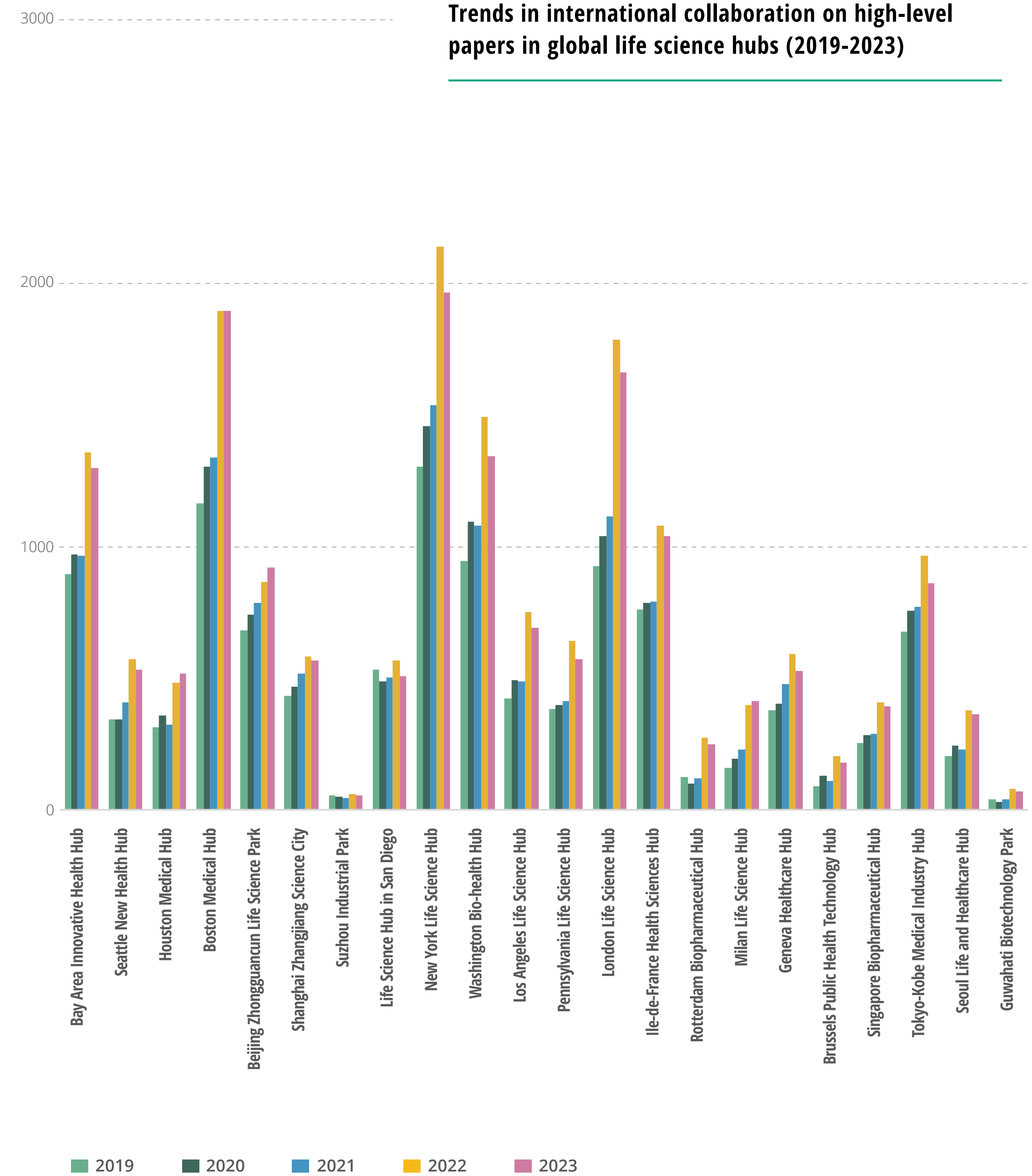


Table 1

Comparison of compound annual growth rates of papers in global life science hubs (2019-2023)

No.	Hub	CAGR of papers in life sciences (2019-2023)	CAGR of papers in biological sciences and health sciences tracked by the Nature Index (2019-2023)	CAGR of internationally co-authored papers in biological sciences and health sciences (2019-2023)
1	Bay Area Innovative Health Hub	3.76%	7.75%	9.71%
2	Seattle New Health Hub	2.93%	13.09%	11.41%
3	Houston Medical Hub	3.80%	14.21%	13.33%
4	Boston Medical Hub	3.64%	10.80%	12.97%
5	Beijing Zhongguancun Life Science Park	8.90%	13.75%	7.89%
6	Shanghai Zhangjiang Science City	9.61%	14.53%	7.11%
7	Suzhou Industrial Park	12.91%	9.05%	0.95%
8	Life Science Hub in San Diego	1.27%	-0.48%	-1.20%
9	New York Life Science Hub	3.97%	9.59%	10.87%
10	Washington Bio-health Hub	1.99%	9.16%	9.27%
11	Los Angeles Life Science Hub	4.81%	12.82%	13.20%
12	Pennsylvania Life Science Hub	3.63%	11.14%	10.67%
13	London Life Science Hub	2.46%	15.73%	15.76%
14	Ile-de-France Health Sciences Hub	0.74%	8.77%	8.11%
15	Rotterdam Biopharmaceutical Hub	2.45%	24.72%	19.78%
16	Milan Life science Hub	7.31%	28.87%	27.07%
17	Geneva Healthcare Hub	4.22%	7.44%	8.79%
18	Brussels Public Health Technology Hub	5.83%	19.82%	19.42%
19	Singapore Biopharmaceutical Hub	4.42%	9.43%	11.61%
20	Tokyo-Kobe Medical Industry Hub	2.58%	8.09%	6.31%
21	Seoul Life and Healthcare Hub	1.86%	17.63%	15.62%
22	Guwahati Biotechnology Park	17.17%	15.33%	16.86%

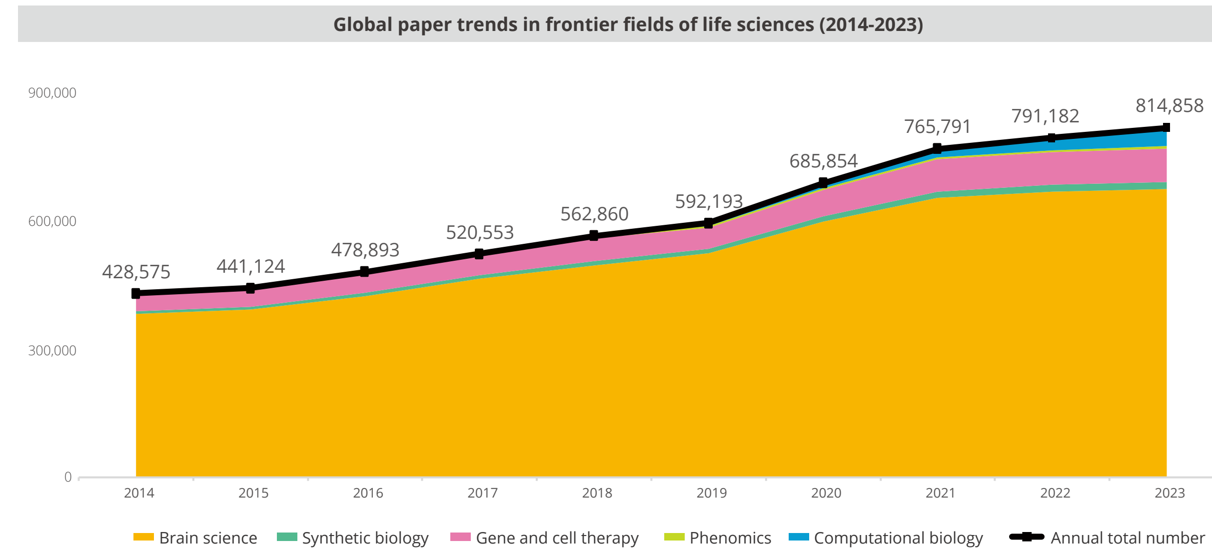
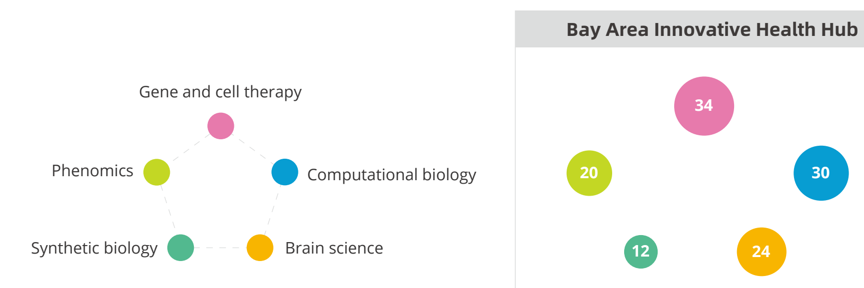
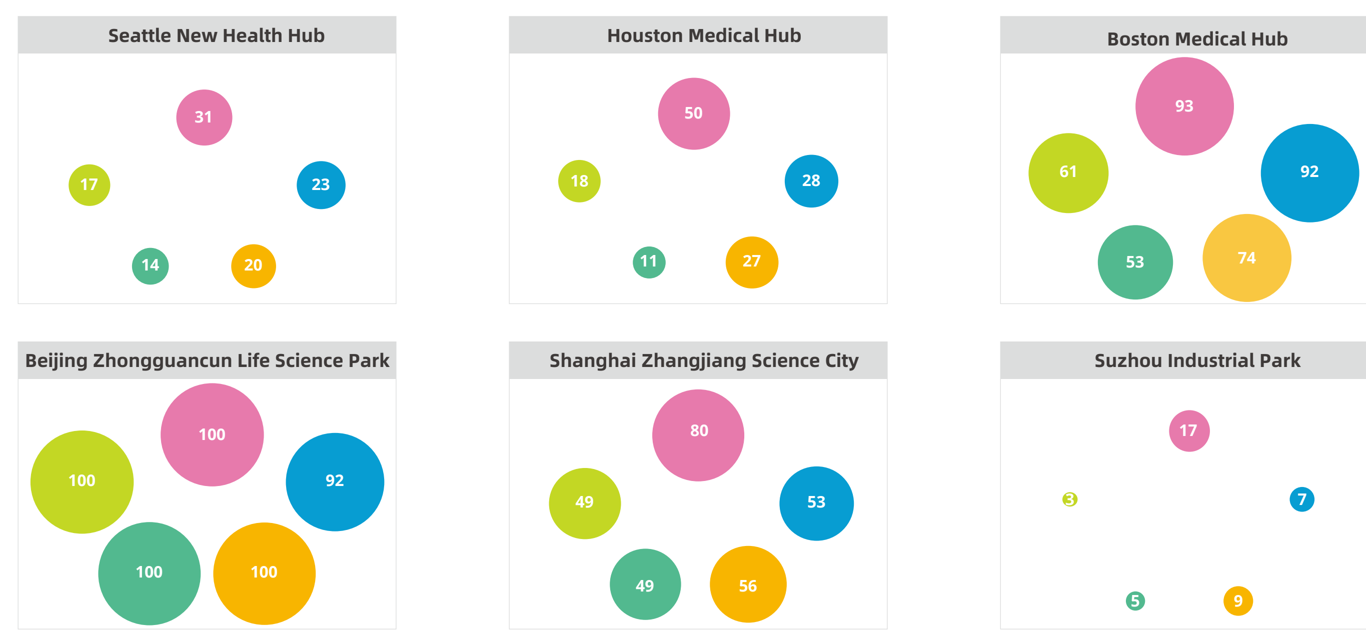
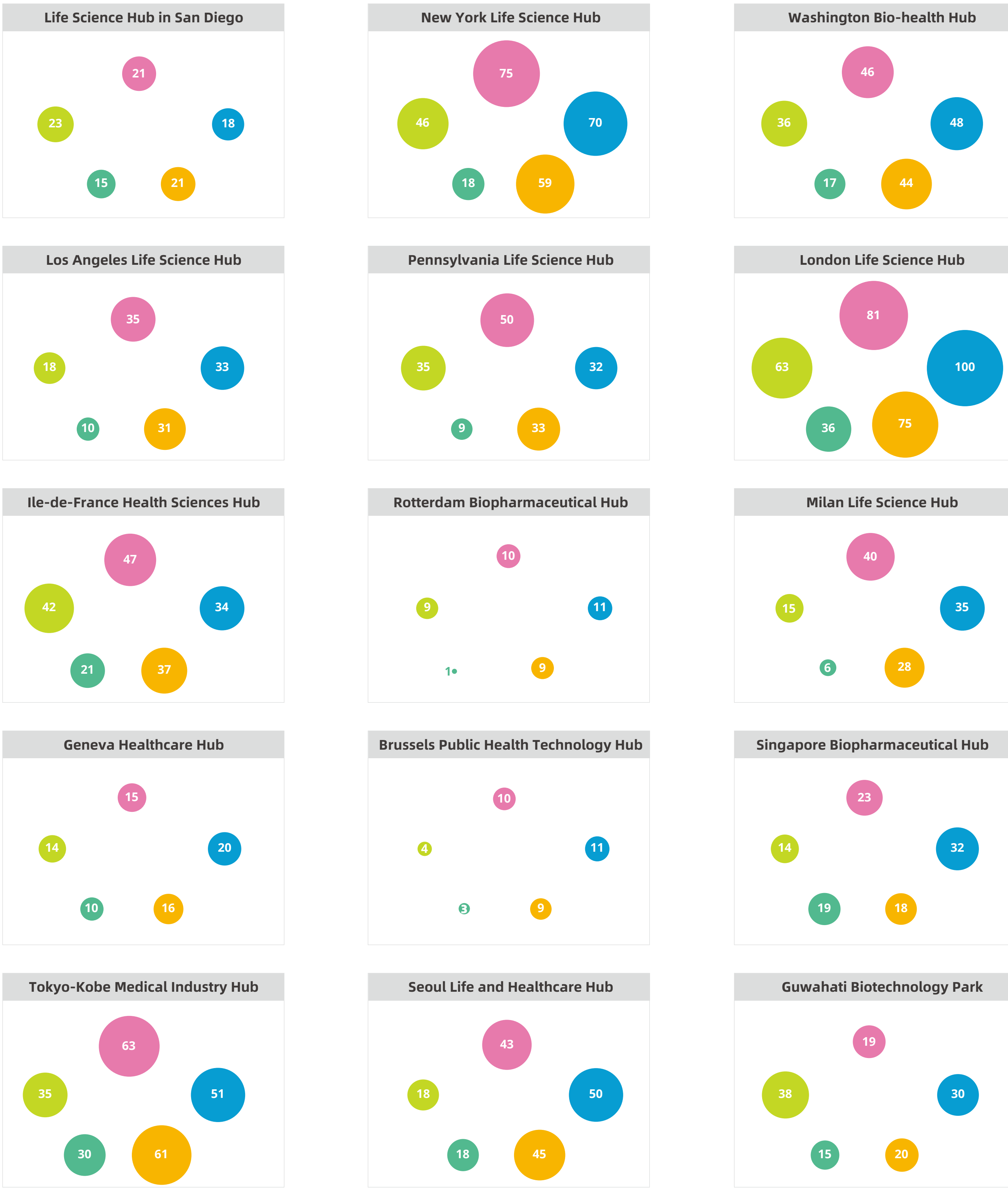


Figure 7

Development trends of global life science frontier areas and hub activity distribution (2019-2023)





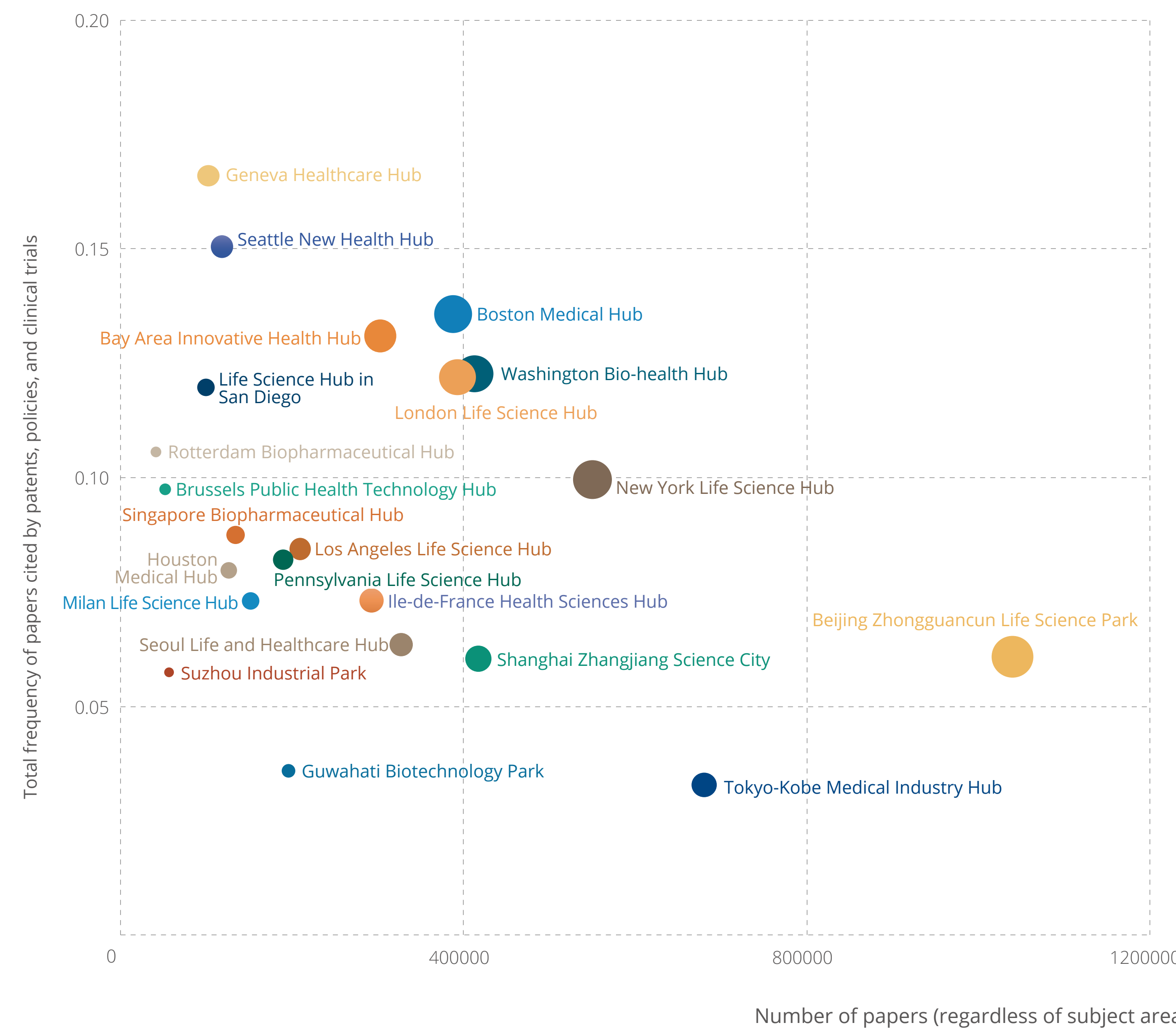


3.3 Research output and commercialization

The two-way link between basic research and industrial innovation is crucial in driving growth within global life science hubs. In these important hubs, businesses and research institutions are geographically close, fostering close interactions and sharing of talent, research infrastructure, and knowledge resources. Governments and local hub management agencies actively promote the collaboration between businesses and research institutions. These efforts catalyze the rapid translation of basic research findings into market applications and commercialization attempts. At the same time, problems discovered during application — issues that cannot be solved through engineering optimization — are fed back to the basic research community,

Figure 8

Total and average citation frequency of global life science hub papers in patents, policies, and clinical trials (2019-2023)



where innovations and breakthroughs can address these challenges. This dynamic interaction between research and industry accelerates the development and practical implementation of new technologies and solutions.

Hubs that are primarily driven by businesses tend to have stronger patent output capabilities. The trend in patent numbers reflects the innovation capacity of these hubs. A study of patent data from major global life science hubs shows that, since 2019, the hub with the highest annual patent total is the Tokyo-Kobe medical industry hub, where Tokyo-Kobe itself accounted for more than 160,000 patents in 2023. This hub has maintained a steady patent output in recent years, with large enterprises in the area continuously contributing technological and innovative achievements to scientific advancement. Following this is Beijing's Zhongguancun Life Science Park, which reached 130,000 patents in 2023, driven by pharmaceutical companies such as BeiGene, demonstrating a high patent output. In terms of growth rate, Delhi had a compound annual growth rate of 30.35%, indicating rapid growth, albeit with a smaller patent base. Beijing's compound annual growth rate was 10.56%, highlighting that while its total patent output is high, it also sees substantial annual growth, becoming a key driver of technological and industrial development in the Beijing life science hub.

Regions with a concentration of universities, research institutes, and businesses tend to have stronger application and commercialization capabilities. The frequency with which papers are cited in patents, policies, and clinical trials is often used to study the activity of basic scientific research transitioning into industry. Data from 2019 to 2023 shows that Beijing's Zhongguancun Life Science Park has the highest citation frequency globally, with a total of about 63,000 citations. Other leading hubs, such as those in New York, Boston, and Washington, have citation frequencies exceeding 50,000, while London and the Bay Area each have totals above 30,000. Shanghai's Zhangjiang Science City has more than 25,000, and hubs in Tokyo-Kobe, Paris, and Seoul have totals exceeding 20,000, with the remaining hubs having fewer than 20,000. These regions host numerous top universities, research institutes, and companies, accelerating the interconnection of knowledge, information, and data, facilitating bidirectional links between science, technology, and industry, and enhancing the translation of ideas into products. When looking at the average citation frequency of papers in patents, policies, and clinical trials, hubs in Geneva and Seattle have an average citation frequency exceeding 0.15. Hubs in Boston, the Bay Area, Washington, London, San Diego, Rotterdam, and New York have an average citation frequency above 0.099. Hubs in Brussels, Singapore, Los Angeles, Philadelphia, Houston, Paris, Milan, and Seoul have an average citation frequency exceeding 0.062. The average citation frequency of papers in Beijing, Shanghai, and Suzhou falls within the range of 0.05 to 0.061. The remaining hubs have an average citation frequency below 0.05.

Life science hubs are the product of efficient operation within innovation ecosystems. The data analysis above shows that Beijing's Zhongguancun Life Science Park is the hub with the most intensive, most active, and fastest-growing activities in the conversion of basic scientific research into industry. Through cooperation with domestic and international enterprises, the Zhongguancun Life Science Park has accelerated the commercialization of biotechnology and pharmaceutical technologies. This includes partnerships with globally renowned pharmaceutical equipment companies such as Danaher, promoting the implementation of synthetic biology manufacturing platforms. Specialized incubation and acceleration platforms such as the Dart International Innovation Platform, New Nest Innovation Centre, and Yuan Yi Digital Medical Accelerator have been introduced to continuously link high-end resources across the industrial chain for startups, facilitating the transition from R&D innovation to industrial implementation. The effective operation of this ecosystem has not only enhanced the hub's innovation capacity but has also significantly shortened the time required for the commercialization of scientific research outcomes. The medical industry hub in Tokyo-Kobe is also active in the industrialization of basic scientific research, though it has shown little significant change in growth. The historical life science hubs in Europe and North America have already accumulated considerable experience in transforming basic scientific research into industry and have maintained stable growth. For example, in Boston's pharmaceutical hub, close cooperation between universities such as Harvard and MIT and enterprises has formed a powerful collaborative innovation ecosystem. For instance, Harvard University has partnered with Pfizer to establish an innovation lab focused on early-stage biotechnology and pharmaceutical innovations. Additionally, Boston has many biotech incubators and venture capital firms that regularly hold innovation competitions and seminars, promoting the rapid transformation of research outcomes into commercial applications. It is important to note that the frequency data above is not limited to the hub locations themselves. The global sharing of paper and patent data means that the impact of basic research outcomes is not confined to local or national boundaries but is also recognized by global enterprises and investment institutions. However, geographical proximity facilitates communication, and therefore, in the commercialization of basic research, there is a tendency to choose collaborators within the same city, region, or even the same park.

Developed economies and emerging markets are leveraging their respective advantages to enhance the influence of their life science hubs. There are notable regional differences in the level of collaboration between basic research and industry within global life science hubs. Life science hubs in developed countries, particularly in the United States, have a significant advantage in patent innovation and industrialization integration. Patent technologies are not only widely cited in academia but also have a profound impact on global research activities in related fields, continuously enhancing

the innovation ecosystem's capacity in these regions. At the same time, emerging hubs in Asia, especially Beijing and Singapore, are demonstrating strong innovation momentum and international research influence, indicating the rise of these regions in global innovation development. The effectiveness of transforming scientific research outcomes into applications in life science hubs is reflected not only in the sustained growth of patent numbers but also in their broad influence within academia and industry. The patent citation rates and ripple effects of hubs in developed countries are particularly striking, showing the central role these regions play in driving scientific research and industrialization. Meanwhile, hubs in emerging markets also show a strong trend in patent growth and some academic influence, further confirming that global innovation activities are rapidly diversifying. Many life science hub management agencies accelerate the transformation of research outcomes into practical applications through information resource-sharing mechanisms such as joint laboratories and technology transfer centres. Additionally, various seminars, innovation competitions, and other events are frequently held within these hubs, further promoting communication and collaboration between academia and industry.

How to make basic scientific research benefit mankind is a widely discussed issue and a powerful driver of human development. The clustering of the life science industry has already optimized this crucial link in an inherently self-organizing way, and the management organizations within these hubs can further catalyze this process through various methods. For a hub, close cooperation between basic research and industry is also a core driving element of its innovation capacity.

3.4 Summary

A systematic analysis of the talent distribution, scientific paper output, international cooperation networks, and the trend of technological achievements' application and transformation across global life science hubs reveals some key patterns. The developed-country hubs, represented by Boston, New York, the San Francisco Bay Area, London, and Tokyo, have relied on their traditional advantages in life sciences to gather a large number of top institutions and high-level talent. They produce high-quality research outcomes, particularly in smaller hubs, which exhibit a higher concentration in life sciences, benefiting the in-depth development of the field. Europe's high level of international cooperation has made it an important hub for global collaboration in life sciences.

Emerging hubs, represented by Beijing, Shanghai, Suzhou, and Delhi, dominate in terms of the scale of researchers, scientific papers, and technological achievements' application and transformation. These regions benefit from a demographic dividend and are growing rapidly, emerging as a new force in global life sciences. However, these emerging hubs show lower concentration in life sciences, reflecting a trend of diversified development that favors interdisciplinary integration. These hubs are also actively integrating into the global innovation network. With the ongoing advancement of global science and technology, the trend of interdisciplinary integration is becoming more pronounced. The innovation practices of life science hubs will become more diverse and dynamic, ushering in new leaps forward.

Chapter 4

Global life science hub innovation practices

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The innovation and development of global life science hubs are constantly evolving. Unique life science hub development models have gradually formed in different parts of the world. Although there are slight differences in organizational structures, there are still many common elements. Identifying and coupling these common elements are key to the innovative development of local life science hubs. These elements include the innovation-driven efforts of research institutions, the global R&D, clinical trials, and market resource integration of multinational companies, the empowerment of parks, venture capital funding, and major scientific infrastructures in the life science field. These factors are evident in the innovation and development of global life science hubs.

4.1 Boston — A high-level model of life science innovation ecosystem

Diverse scientific entities continuously spark innovative through collaboration. From the "Eastern Silicon Valley" to the "Massachusetts Miracle," the innovative development of the Boston life science hub is no accident. The key to success lies in the hub effect brought by the diverse innovative entities within the region. From the perspective of innovation sources, Boston has gathered more than 30 universities and more than 40 research hospitals, including the Massachusetts Institute of Technology (MIT), Harvard University, Boston University, and the Dana-Farber Cancer Institute. These research institutions have made significant breakthroughs in cutting-edge technologies such as gene editing, single-cell sequencing, brain science, anti-aging, and 3D organoid culture, providing strong support for the development of the entire life sciences field. From the perspective of market entities, many multinational companies have established a presence in Boston, including AstraZeneca, Thermo Fisher, Novartis, Pfizer, Bayer, Genentech, and Millennium Pharmaceuticals. Their goal is to attract top talent and leverage the local innovation ecosystem. Many of these market entities collaborate extensively with academic and research institutions, rapidly translating cutting-edge scientific technologies into commercial applications and industrial development. For example, MIT and Verve Therapeutics developed a gene-editing therapy to lower cholesterol, marking a major breakthrough based on CRISPR technology. Harvard University successfully created functional pancreatic cells in vitro, which were later commercialized through Semma, a biotechnology company, and subsequently acquired by Vertex Pharmaceuticals.

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New types of research organizations and professional service institutions driven by innovation demand have emerged. In Boston, with the rapid rise of life science enterprises, the demand for innovation development has been growing. In 2008, the Boston Life Sciences Center (CLSB) was established, becoming a significant milestone in the innovative development of the Boston life science hub. Located in the Longwood Medical Area, it is the tallest building in the region and the largest research centre, with the goal of becoming a world-class R&D hub. The Boston Life Sciences Center is a model of collaboration between local government, private medical research institutions, and market financing. Research-oriented medical institutions such as the Wyss Institute for Biologically Inspired Engineering, Pfizer Innovation Center, Dana-Farber Cancer Institute, and Boston Children's Hospital have successively settled in the Boston Life Sciences Center, creating a hub for life sciences innovation. Additionally, new life science laboratory incubators, such as the Verve Lab and Nest Lab, have been established in Kendall Square. Compared to universities and research institutions, these labs focus on solving the "1-10" problem, accelerating the commercialization of laboratory results. As of now, these new life science incubators have successfully incubated a batch of high-level tech enterprises, including HiFiBio Therapeutics, Engine Bio, and Bota Biosciences, which have made significant breakthroughs in areas like single-cell technology, synthetic immunology, and protein degradation.

The highly concentrated venture capital in the global life sciences sector has created a virtuous cycle of "innovation-development-reinnovation". Globally, the area with the most concentrated venture capital in life sciences is undoubtedly Kendall Square in Cambridge, Boston, which is home to over 80 venture capital firms in the field. According to various life science databases and publicly disclosed information, more than a hundred pharmaceutical companies have completed IPOs or been acquired by leading companies in the region. In particular, top multinational companies from the industry have become an essential "fuel" for Boston's cycle of innovation to industrialization. For example, Sanofi made a massive investment to acquire the U.S. biotech firm Genzyme, and Takeda Pharmaceuticals invested heavily to acquire Millennium Pharmaceuticals. In addition to abundant global venture capital, annual entrepreneurial competitions held in Boston provide important platforms for the active involvement of these venture capitalists. These include events like the MGH Translational Medicine Conference, BCIC International Biomedicine Venture Competition, MIT Entrepreneurship Competition, Harvard Innovation Lab, the American Chinese Biopharmaceutical Technology Association's Entrepreneurial Competition, and the Boston Health Tech Entrepreneurship Competition, among others. Thus, it is evident that the path of the 128 Highway in Boston's life science hub, driven by innovation and revitalized repeatedly, is truly unique.

4.2 Seattle - Establishing a cross-regional R&D and production cooperation system for life sciences

It has a rich endowment of life and health innovation resources. Seattle, located on the U.S. West Coast, is home to a wealth of advanced medical institutions and research centres, including the Fred Hutchinson Cancer Research Center, the University of Washington, the Virginia Mason Medical Center, and the Seattle Children's Research Institute. It also boasts the world's largest cancer control and prevention research programme. According to a study published by the University of Leuven, Belgium, in *Nature Biotechnology* in early 2024, the Seattle area holds 4,783 patent families and has 2,486 research projects funded by the National Institutes of Health (NIH), with a

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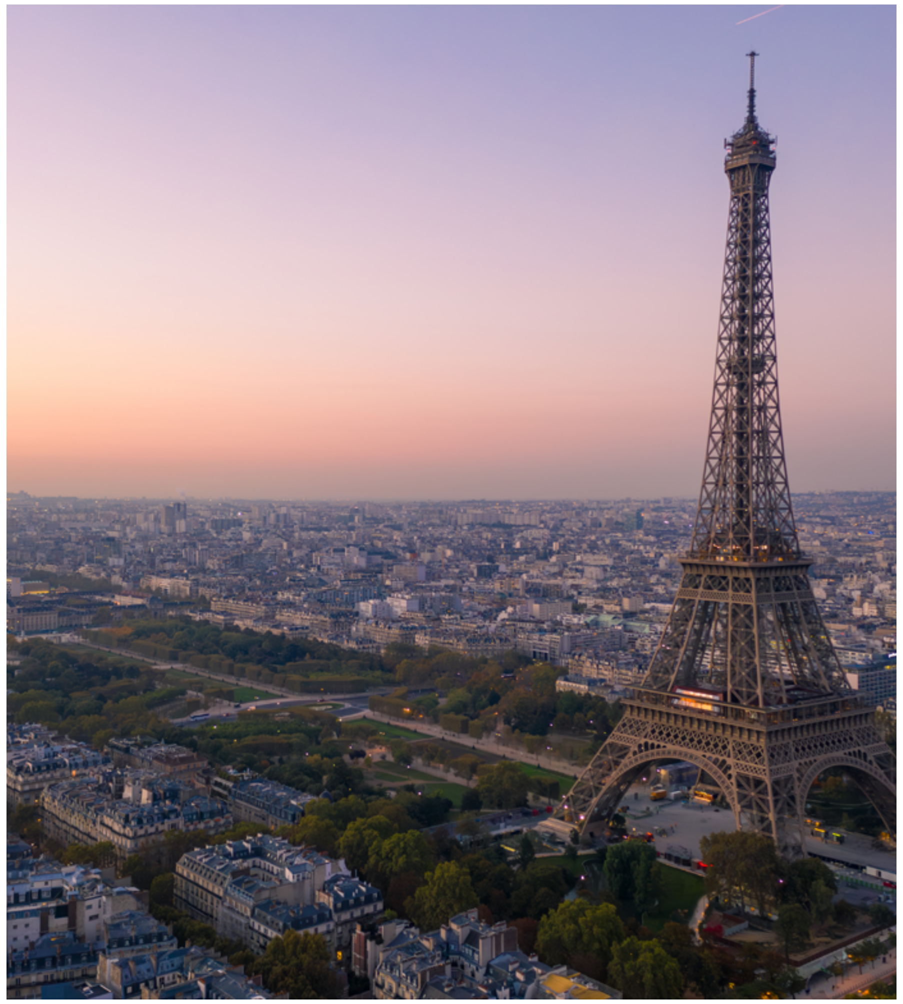
total research funding of $1.842 billion. In 2023 alone, Seattle secured $854.5 million in life sciences investments. In terms of laboratory space, Seattle offers more than 8.5 million square feet of lab space. In the life sciences job market, the city provided more than 46,500 jobs in 2022. These achievements place Seattle in the top ten U.S. cities in the life sciences sector, showcasing the region's exceptional scientific accomplishments and market-oriented results in recent years.

Establish a cross-departmental and cross-regional special planning and implementation committee in the field of life sciences. In 2018, the Cascadia Innovation Corridor, linking Seattle, Portland, and Vancouver, Canada, was launched. A key initiative within this corridor was the establishment of the Life Sciences Committee, which includes leaders from the Seattle Children's Research Institute, the Bill & Melinda Gates Foundation, Fred Hutchinson Cancer Research Center, Kaiser Permanente, and Vancouver's Ernst & Young Life Sciences Advisory Committee, among others. This committee took the lead in creating a specialized life sciences development plan for the Cascadia Innovation Corridor. The plan outlined specific strategies to accelerate life sciences cooperation between the three regions, including frameworks for data sharing and usage, and the establishment of networks for regional life sciences innovation and research collaboration. Building on this, the plan set a series of critical milestones. This cross-departmental and cross-regional life sciences plan received collaborative support from government agencies, research institutions, and investment funds, which significantly contributed to the rapid development of the life sciences industry in the Seattle area.

Explore and establish a new open mechanism to serve the innovative development of life sciences. Seattle, Portland and Vancouver jointly established the Cascadia Venture Acceleration Network (CVAN), which enables 50 organizations such as universities, incubators, investment funds, and industry associations to collaborate in innovation. On this basis, the Seattle-Vancouver Financial Innovation Network was also established to create a three-dimensional support network of "creativity, technology, and capital". Through "identifying valuable innovative projects in the field of life sciences, providing cross-border financial support for entrepreneurs, connecting various scientific research resources, and sharing various activities and platforms", it helps innovative projects and new technology companies to quickly establish a cooperative network and improve the efficiency of resource integration in the field of life sciences. Based on data science, studying and optimizing the challenges faced by scientific and technological innovation is a new exploration of this hub. The University of British Columbia and the University of Washington jointly established the Cascadia Urban Analysis Collaborative, which invests more than US$5 million in research funds each year to establish a public-private data sharing application platform to analyze and solve important issues closely related to innovation such as urban construction, transportation, and population. In addition to these initiatives, Cascadia continues to enhance cross-regional connectivity. To better coordinate work and life across the three regions, some co-working spaces have introduced the "Cascadia Passport Program." This program allows global members holding the passport to use shared office spaces and meeting rooms in Seattle, Vancouver, and Portland for a limited time, facilitating the coordination of research, work, and life in cross-regional life sciences collaborations[16].

4.3 Paris - A biomedical innovation hub based on international clinical research advantages

Driven by top research institutions to foster original knowledge creation.



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The rise of the Paris life science hub is primarily attributed to the presence of numerous world-class life sciences research institutions. In the field of applied basic research, major institutions such as the French National Institute of Health and Medical Research (INSERM) and the French National Centre for Scientific Research (CNRS) have their headquarters in Paris. Among them, INSERM is the largest biomedical research institution in Europe, with 9 research institutes covering over 50 life health disciplines, including cell biology, gene therapy, and epidemiology. The CNRS Life Sciences Research Institute (INSB) focuses on basic research areas such as biological complexity, molecular biology, and genomics, actively promoting interdisciplinary fusion research through CNRS's extensive research network. In terms of specialized biomedical research, Paris is home to world-renowned institutions like the Pasteur Institute, the Curie Institute, and the Gustave Roussy Institute. The Pasteur Institute is a global leader in infectious diseases and immunology, having produced 10 Nobel laureates. The Curie Institute focuses on cancer research and leads cutting-edge studies in areas like cell and gene therapy, immunotherapy, and organoid chips. Additionally, Paris hosts the top French universities in life sciences, including Sorbonne University, University Paris-Saclay, and Pierre and Marie Curie University, providing comprehensive support for basic life sciences research in the region. In terms of international scientific collaboration, Paris has built a life sciences research network that radiates throughout Europe and globally, relying on its top-tier research institutions. For example, INSERM operates around 350 research branches in France and around the world, while the Pasteur Institute has more than a dozen branches both locally and overseas.

Create an international clinical research centre through a large-scale hospital network. According to Choose Paris Region, about 10% of the world's international clinical research is carried out in Paris, providing strong support for the clinical application and transformation of basic research results in life sciences in Paris[17]. Paris has the largest hospital network group in Europe, the Paris Public Hospital Group (AP-HP). The Paris Public Hospital Group consists of 39 hospitals, each of which has unique advantages in a specific medical field. Notably, the Pitié-Salpêtrière Hospital and the Georges Pompidou European Hospital have been ranked among the best hospitals globally by *Newsweek*, particularly renowned for their expertise in cardiovascular medicine, minimally invasive surgery, neuroscience, and brain science. In addition to AP-HP, Paris also has over 250 other hospitals, covering a wide range of medical disciplines.

Fostering a biomedical industry hub based on foundational and clinical research. Leveraging world-class research institutions and hospital networks, Paris has attracted more than 1,000 life sciences companies and more than 56,000 upstream and downstream companies related to the biopharmaceutical industry. This has led to the formation of several life science industry hubs, such as Medicen (Île-de-France Health Innovation Center), Genopole (located in Evry-Courcouronnes, south of Paris), and Biocitech (located in Romainville). Among them, Medicen focuses on biotechnology, medical technology, and digital health, bringing together more than 450 life science-related enterprises, academic institutions, hospitals, and organizations. This includes top-tier research institutions such as INSERM, INSB, the Pasteur Institute, and the Curie Institute; well-known hospitals like Saint-Joseph Hospital, Gustave Roussy Cancer Center, and Foch Hospital; prestigious universities such as Sorbonne University, Paris University, and Paris-Saclay University; and large multinational corporations such as Sanofi and Boehringer Ingelheim. This creates a life sciences innovation hub that integrates research institutions, hospitals, universities, and enterprises, becoming a key driver of France's life sciences development.

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4.4 Beijing — A strategic innovation hub that integrates top scientific research resources

Creating a hub for life sciences innovation driven by top-tier universities and research institutions. The pharmaceutical and health industries are one of the key engines driving innovation in Beijing's development, with Changping being a focal point for cultivating and developing these industries. Over years of development, the Zhongguancun Life Science Park in Changping has become one of the most concentrated innovation resource hubs in China's life sciences field, serving as the innovation engine for Beijing's pharmaceutical and health industries. The park houses numerous high-level research universities and institutions. Within the park, the Beijing Zhongguancun Life Science Park gathers over 10 world-class research institutions, including Changping Laboratory, Beijing Institute of Life Sciences, Beijing Brain Science and Brain-like Research Institute, and the National Protein Science Center. It also hosts leading hospitals such as Peking University International Hospital, Gaobo International Research Hospital, and Peking University Sixth Hospital. Surrounding the park are areas rich in research resources, such as the Chinese Academy of Sciences, Peking University, and Tsinghua University, all of which contribute to an excellent academic atmosphere and a highly concentrated network of top-tier research resources. Supported by world-class foundational research and clinical medicine resources, the Zhongguancun Life Science Park has established a global leadership in areas such as small molecule drugs, cell and gene therapies, and digital healthcare. In the field of small molecule drugs, the park has made significant breakthroughs through independent research and international cooperation, such as the first anti-cancer drug developed by a Chinese company, Zebutinib, which was approved for sale in the U.S., as well as discoveries related to cell death and anti-tumour immunity. In cell and gene therapies, the park has become a core R&D base for China's gene editing technology, built upon cutting-edge research from institutions such as the Chinese Academy of Sciences and Peking University. It has achieved major breakthroughs, including chemically induced reprogramming of human cells and the development of gene therapy drugs for diseases like ALS, based on exclusive targets. In digital healthcare, the park is also highly competitive on the global stage, with achievements such as the world's first AI-assisted diagnostic medical device for coronary artery stenosis, registered as a cardiovascular AI diagnostic software.

Leading with cutting-edge technologies to create an innovation hub for the medical and health industries. Leveraging the dense concentration of universities, research institutions, and hospital resources, the Zhongguancun Life Science Park in Beijing focuses on frontier fields such as cell and gene therapies, digital healthcare, synthetic biology manufacturing, and next-generation antibodies. The park aims to become a globally competitive hub for the development of the pharmaceutical and healthcare industries. It has attracted over 600 innovative biopharmaceutical companies, including BeiGene, Innovent Biologics, and Wantai Biopharma, as well as multinational R&D centers like Novo Nordisk and Boehringer Ingelheim, along with cutting-edge enterprises founded by renowned scientists in fields such as Vitrolife, Yanming Biotech, and YouBrain Galaxy. The park has successfully formed an ecosystem encompassing the entire industry chain, from basic research, pilot R&D, production, and distribution to end-user medical applications. In areas such as incubation acceleration and pilot R&D, the park has gathered more than 50 specialized innovation service platforms. These include international research hospitals, the Beijing Major Disease Clinical Biobank Public Service Platform, the Zhongguancun AI New Drug R&D Platform, the full-function cryo-electron microscopy service platform, the CDMO platform for cell and gene therapy, the pilot-scale public service platform for large-molecule drugs, and the Changke Huaguang Medical Device (CMO) platform. Additionally, the park has established a comprehensive public service system, offering support through platforms such as the Beijing Pharmaceutical and Medical Device Innovation Service Station, the "Changsheng Yizhan" government service scene, an international talent activity room, an expatriate service hall, and a Free Trade Zone hub registration platform. These services provide full support to the development of enterprises. Currently, the Zhongguancun Life Science Park is experiencing rapid development, with various platforms and innovative companies continuing to accelerate their growth and aggregation.

Build an open industrial innovation ecosystem supported by professional operation services. First, rely on professional operation teams to create an international industrial innovation ecosystem. Beijing Zhongguancun Life Science Park relies on the three professional service platforms of Future City Company, Chang Development Company, and Life Park Company to build an industrial innovation ecosystem of "full-process project management + full-chain incubation investment acceleration + all-round park operation services", providing life science and technology companies with one-stop integrated services from site selection, fund guidance to achievement transformation. Second, rely on national planning and policy advantages to build a high-level industrial innovation park. Beijing Zhongguancun Life Science Park has the development advantages of the four superimposed areas of Zhongguancun National Independent Innovation Demonstration Zone, National Service Industry Comprehensive Demonstration Zone for Expanding Opening, China (Beijing) Pilot Free Trade Zone Science and Technology Innovation Zone, and Beijing High-level Talent Highland. It has multiple advantages such as resource aggregation, institutional openness, and flexible mechanisms, and has become an important carrier for Beijing to build a world-leading life science and technology park. Third, create a world-class industrial carrying space for all-region resources. With Beijing Zhongguancun Life Science Park as the core, a number of standard pharmaceutical and health factory projects have been built. The main structures of the three projects, International Precision Medicine Industrial Park, International Bioengineering Innovation Center, and Kexing High-tech Achievement Transformation Base, have been completed. Starting from 2024, they can provide high-quality standard factory space of about 500,000 square metres. According to the spatial layout of "one core, one belt and two areas", the life science innovation corridor will be built at an accelerated pace. With the life science park as the core, Beijing-Xinjiang and Beijing-Tibet Expressways will extend northward as the main axis, and a number of industrial projects such as Life Valley International Pharmaceutical Intelligent Manufacturing Park and International Medical Device City will be implemented in stages. In the next 3-5 years, 4.5 million square metres of high-quality pharmaceutical and health industry space will be newly supplied. Fourth, a series of support measures have been introduced for key areas and links of the pharmaceutical and health industry. The first free trade pilot zone pharmaceutical and health industry development policy has been introduced to accelerate the transformation of innovative achievements, introduce and implement innovative projects, strengthen and upgrade innovative enterprises, and optimize and improve the industrial ecology. Nearly 100 million yuan of funds was redeemed in 2022, and the policy was optimized and upgraded to its 2.0 version in 2023. The Beijing Municipal Government Investment Guidance Fund established the Beijing Pharmaceutical and Health Industry Investment Fund with a registered capital of 20 billion yuan. It will focus on investing in key industrial fields such as innovative drugs, innovative medical devices, and emerging industrial fields such as cell and gene therapy, digital medicine, etc. It was registered and established in the Life Science Park in 2023.

4.5 Shanghai — A pioneer in embedding Chinese life sciences into international innovation networks

The spatial concentration and continuous support of the "government-industry-academia-research-finance" ecosystem. In recent years, driven by innovation-led development and the ambition to build a globally influential science and technology innovation centre, the life science innovation hub in Shanghai has accelerated its development, gradually shifting from the "foundation-building" and "framework-building" stages to a focus on "strengthening functionality." Notably, Shanghai Zhangjiang has become a key hub for the concentrated development of the "government-industry-academia-research-finance" ecosystem. Zhangjiang is home to high-level life science research institutions such as ShanghaiTech University, Shanghai University of Traditional Chinese Medicine, and the Institute of Materia Medica, Chinese Academy of Sciences. Leveraging the Zhangjiang platform's ecosystem, a growing number of innovative companies with strong "hard-tech" capabilities have been incubated. Additionally, the scale of domestic venture capital in Zhangjiang's life science sector is relatively ample. In 2021 and 2022, the number of life science-related venture investments in Zhangjiang accounted for 7% and more than 8%, respectively, of the total national venture capital[18]. At the same time, Zhangjiang has become a testing ground for the implementation of new policies. For example, the pilot program

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for the Market Authorization Holder (MAH) system for drug licensing was first launched in Zhangjiang. This reform allows drug development and production to be separated, greatly improving the speed at which drugs reach the market. Some pharmaceutical companies have managed to shorten the time to market for new drugs by nearly two years, saving over 100 million yuan in production line investments. Moreover, in September 2024, the Ministry of Commerce, the National Health Commission, and the National Medical Products Administration issued a notice on expanding the opening-up pilot in the medical field. This policy allows foreign-invested enterprises to engage in human stem cell and gene diagnostic and therapeutic technology development and applications, breaking previous restrictions in Beijing, Shanghai, Guangdong Free Trade Zone, and Hainan Free Trade Port. This will facilitate the registration and production of related products in these sectors.

Shanghai is a key hub for domestic and international collaboration in life sciences. A survey of the life science universities, research institutions, and companies in Shanghai Zhangjiang has found that more than 4,000 globally renowned scientists are concentrated in this area. Of these 4,000 scientists, 60% have overseas experience, coming from 44 different countries. A clearer picture emerges when analyzing international scientific paper collaborations. Zhangjiang's universities, research institutes, and tech-driven enterprises have collaborated with over 7,600 institutions from 120 countries, and accumulated more than 400 international patents, making it an important source of global life science innovation. Statistics show that between 2015 and 2022, Zhangjiang completed 46 cross-border License Out transactions, totaling 103.3 billion yuan, and 142 cross-border License In transactions, totaling 105 billion yuan, accounting for one-quarter of the entire nation's total. In domestic License transactions, Zhangjiang exported around 50 technology projects to Jiangsu, Zhejiang, and Anhui, representing more than half of the total number. This highlights that the development of Shanghai's life science innovation hub is closely supported by global networks and the Yangtze River Delta region.

The hub of major scientific infrastructure is driving breakthrough innovations in basic research in Shanghai's life science field. The concentration of major scientific facilities, such as the National Protein Research Facility, the Live Cell Structural Line Station Project, the Liver Cancer Medical Center, the Translational Medicine Center, the Synchrotron Radiation Source, and the Cryo-Electron Microscopy, has provided significant support for breakthroughs in basic research within the life sciences in Shanghai. These critical infrastructures have greatly enhanced imaging capabilities in the life sciences, particularly during the pandemic, when the Shanghai Synchrotron Radiation Source successfully conducted protein structure analysis of the novel coronavirus. This provided a strong foundational support for the further development of broad-spectrum targeted drugs against coronaviruses.

4.6 Summary

Looking globally, the development of life science innovation hubs follows a clear trajectory, with the role of ecological empowerment being particularly prominent. Whether in Boston, Seattle, Paris, Beijing, or Shanghai, government guidance, market traction, and investment in innovation are crucial factors driving the development of life science hubs. However, without the nurturing of a robust ecosystem, life science innovation lacks "soul" and cannot spark the "chemical reactions" that typically occur within spatially concentrated boundaries. According to current research, the innovation ecosystem for life sciences requires open, collaborative science parks and industrial parks, long-term "patient capital," open shared laboratories that offer specialized services, as well as major scientific infrastructure and specialized research instruments to serve the industry. Only when these elements are highly concentrated within a region and begin to couple with one another, can a world-class life science hub more easily come into being.

Chapter 5

Opportunities and challenges for the innovative development of global life science hubs

5.1 Challenges and opportunities of life sciences development

The global "capital winter" poses significant challenges to the innovation in life sciences. The biomedical sector worldwide has in recent years been facing liquidity challenges and a cold market for investment and financing, which severely impacted the development of life sciences. Following the impact of "black swan" events like the COVID-19 pandemic, global biotechnology and platform companies have gone through a downward trend in financing since 2021, as the number of biotech IPOs remained persistently low. Although 2024 signals recovery in total venture capital, the phenomenon of "wealth gap" is becoming more pronounced as capital has been increasingly concentrated in popular fields and clinical-stage projects. Patience among investors is generally lacking, and it severely hinders foundational research and original innovation in life sciences. In such cold capital market, numerous biotech startups had to use measures like layoffs and equity concessions to survive, which weakened the overall innovation and entrepreneurial vitality of the biomedical industry[19].

The unique security-sensitive nature of life sciences limits the further deepening of international scientific and technological cooperation. The collaboration in the biomedical field among countries has been getting closer due to the acceleration of globalization, but it is still difficult in many aspects to break through regional barriers. On one hand, frontier research in life sciences often involves human genetic resources such as embryonic stem cells and the human genome, which are closely tied to national biosafety, public health, and personal privacy. When it comes to openness and international cooperation, these resources are often constrained by national policies and regulations, which severely limits the advancement of international clinical research and scientific collaboration. On the other hand, there are significant differences in intellectual property laws, enforcement approaches, regulatory policies, review standards, and market access requirements in the field of life sciences across countries. Multinational companies face complex compliance challenges in expanding international business, which can lead to delays in market entry and additional costs, therefore increasing operational risks and uncertainties. From the perspective of emerging countries or regions like China, the development of life science hubs continues to encounter many bottlenecks and challenges in areas such as cross-border operations, R&D investment, process workflows, specialized services, and integration among companies within the industry.

Breakthroughs in frontier life sciences technologies have introduced new ethical challenges. While ethical debates over cloning technology and embryonic stem cell research continue, advances in next-generation technologies like gene editing, organoid research, and synthetic biology bring additional ethical challenges. If gene editing technology in DNA design is left unbound, it could cause issues such as genetic superiority and discrimination, leading to ethical challenges. Advances in synthetic biology grant us the power to create entirely new biological entities, thus raising numerous questions around the definition of life, biosafety, and bioethics. Organoid research, particularly those with brain organoids, could have profound implications for understanding the origins of consciousness. Ultimately, the potential for life sciences to extend human lifespan — even to the point of achieving immortality — may provoke complex discussions and decisions on related issues such as population and human reproduction.

Innovation in life sciences offers broad application and development potential across other fields. Following the advances in synthetic biology, biomanufacturing, and other biotechnologies, life sciences are emerging as a foundational discipline that will shape future industrial development. Biomanufacturing, one of the most promising technologies for sustainable development in human society, features characteristics like product design ability, renewable raw materials, and green, low-carbon processes. It has extensive applications in critical industries such as energy, chemicals, materials, food, and agriculture. For example, advances in biofuel technology could reduce or even replace the reliance of the energy industry on non-renewable fossil fuels. Artificially synthesized proteins may transform production methods in planting and animal husbandry, significantly impacting the food industry. Bio-based materials can be widely used in packaging, textiles, environmental protection, and industrial manufacturing. Novel "bio plus " production modes — such as bio plus chemicals, bio plus energy, and bio plus light industry — will continue to emerge in the future, driving revolutionary changes in industrial production methods.

5.2 Future of life sciences innovation

A review of recent breakthroughs in life sciences reveals a continuous stream of foundational research and interdisciplinary innovation, indicating that key areas are entering a turning point and peak period of innovative growth.

1. Deep learning for protein design: The field of protein engineering is undergoing a paradigm shift, while deep learning algorithms in artificial intelligence significantly enhance the ability to design functional proteins. These interdisciplinary technologies not only accelerate the development of new enzymes and therapeutic proteins, but also lay a solid foundation for innovative applications in drug delivery and vaccine development. Large language models, which treat protein sequences as language structures, play a crucial role in uncovering the mysteries of protein structure. They speed up the process of creating stable, efficient, and applicable synthetic proteins[22].

2. 3D printing of nanomaterials: 3D printing is advancing into the realm of microscale materials, making it possible to manufacture small-scale functional materials that are especially suitable for pharmaceutical and medical device R&D in life sciences. After overcoming the limitations of traditional techniques in speed, material compatibility, and cost, nanoscale 3D printing enables more sophisticated applications in nanomaterial-based diagnostics and robotics. It signals the arrival of a new era for life sciences powered by advancements in material sciences[23].

3. Super-duper resolution: Innovative technologies like MINSTED and DNA-PAINT now enable observation of biological processes at molecular and atomic levels, which opens new perspectives for understanding complex biological systems and disease mechanisms. MINSTED in particular, is an advanced super-resolution fluorescence microscopy technique based on STED[21].

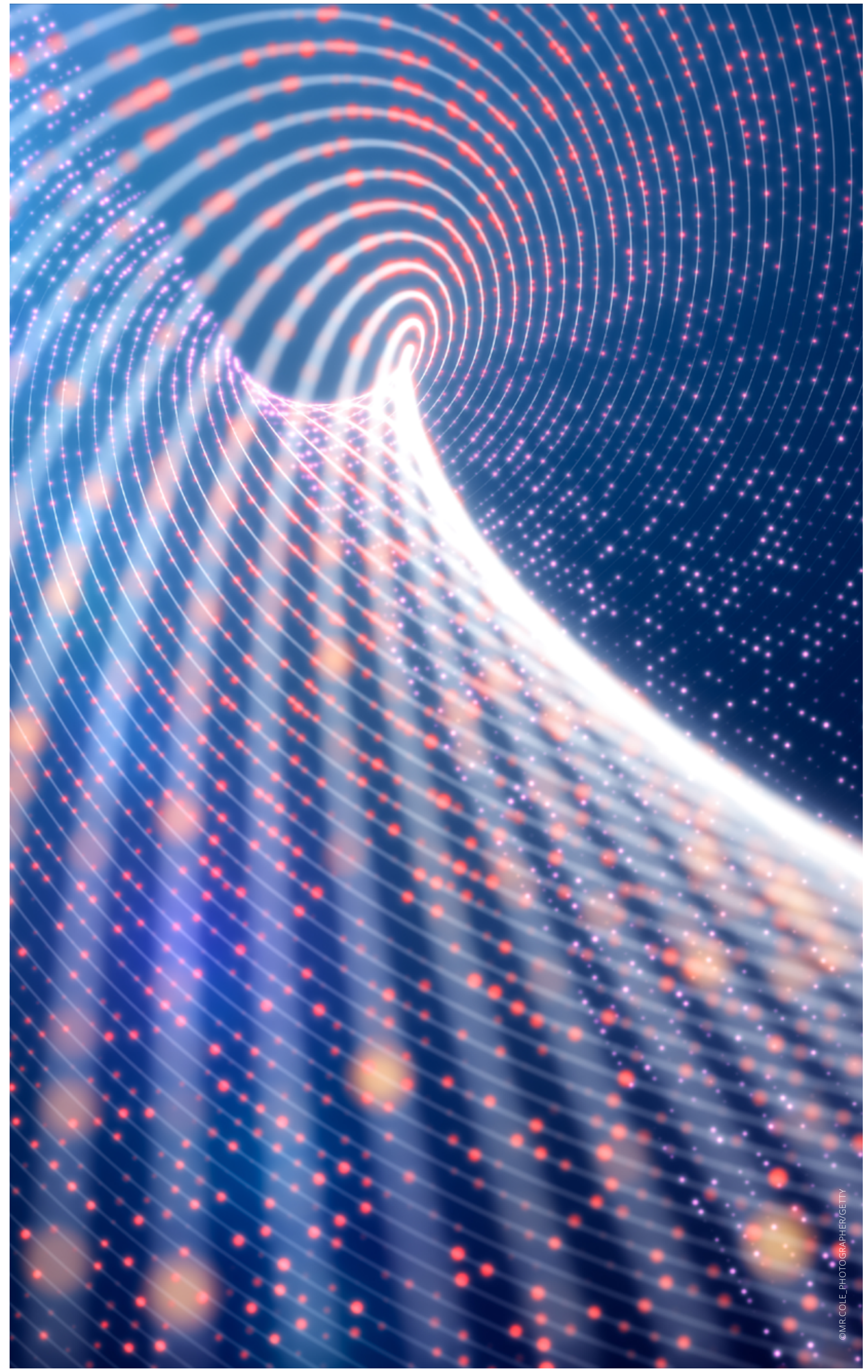
4. Brain-computer interfaces: The Brain-Computer Interface (BCI) technology is transforming the lives who have lost mobility or speech abilities by enabling integrated communication and control through accurate recognition of brain signals. The development of BCI technology not only enhances the quality of life for people with functional impairments, but also opens pathways for broader applications, including the treatment of cognitive disorders, mental health issues, and thought-based control systems[24].

5. Synthetic biology: Synthetic biology has been transforming our methods of production and may profoundly influence our dietary patterns, fuel generation, and the creation of specialized medications. Scientists are currently using yeast as a chassis cell to engineer the production of soy leghemoglobin, adding it to plant-based burgers and making them "indistinguishable" from the real ones[25]. Following the continued growth of the global population, more microbial communities will replace sugar-based raw materials in the coming years and even decades. At the same time, more biochemically synthesized products will replace traditionally chemically synthesized ones, fully leveraging the green, low-carbon, environmentally friendly, and renewable characteristics of bio-based materials[26].

6. Cellular gene therapy: The cellular gene therapy has gained significant attention in recent years, providing new treatment and improvement options for many difficult diseases. However, its high cost limits its accessibility to broader audiences. Recently, scientists have proposed the use of on-demand manufacturing technologies, enabling this new therapy to be produced and applied right by the patient. This approach holds promise for breaking through the price barrier and ensuring that the benefits of these advanced treatments may be more equally accessible to all[27].

5.3 Summary

As cutting-edge technologies continue to break through, life sciences have been rapidly advancing into unknown territories in basic research and expanding into other fields in industrial technology, driving the new wave of scientific and industrial revolutions. On one hand, life sciences are increasingly integrating with other disciplines and emerging technologies. As new fields such as AI-driven drug development, synthetic biology, brain-computer interfaces, and gene editing constantly emerge, they push life sciences into extremely microscopic domains to explore the origins of life. On the other hand, the innovations in life sciences are spilling over into other sectors, accelerating innovation in agriculture, food, energy, chemicals, materials, and other vital industries, which offer hope to achieve a green, sustainable future for human society. However, the ethical challenges and imbalances arising from the development of life science technologies turned out to be more obvious, asking for urgent attention from governments and research institutions worldwide. It is essential to establish an orderly regulatory framework to guide the development of life sciences in ways that benefit human well-being.



Chapter 6 Conclusions

This report provides an in-depth analysis of the driving factors, characteristics, models, and trends in the development of global life sciences industry clusters by examining them as a whole and exploring major case studies in depth. While the development of global life sciences industry clusters presents vast opportunities, it faces numerous challenges as well.

Since life sciences entered the modern molecular and cellular biology era, a multipolar structure has been established in global life science hubs after nearly a century of development. Developed countries like the United States, the United Kingdom, Switzerland, France, and Japan hold a clear advantage in life sciences innovation, positioning themselves as centers of modern life sciences development. Meanwhile life science hubs in Asian countries, such as Singapore and China, are rising rapidly, turning into new growth poles in the industry. Life sciences research continues to delve into highly microscopic scales, extreme conditions, and highly interdisciplinary domains. Therefore, its emphasis on intensive research, high capital investment, long cycles, high costs, and significant risks has been more pronounced, demanding dense concentrations of innovation resources. This will likely intensify the polarization of life sciences cluster development.

Data analysis results based on the utilized database also indicate that foundational research output, international scientific cooperation, and commercialization of research achievements in the global life sciences field predominantly occur in large cities of developed countries, such as the United States, the United Kingdom, France, and Switzerland, as well as in Asian hotspot regions like Beijing, Shanghai, and Suzhou of China. The United States maintains a clear advantage in life sciences innovation, supported by a long-standing foundation in the field that has cultivated numerous top talents, institutions, universities, and companies. Emerging life science hubs in Beijing, Shanghai, and Suzhou are experiencing rapid growth in the application and commercialization of scientific achievements; however, they still lag behind the United States and Europe in basic research and international collaboration.

The rise of life science hubs such as Boston, Seattle, Beijing, Shanghai, and other regions demonstrates that the robust development of these clusters not only requires support from highly skilled scientific talent, research institutions, universities, and tech companies, but a well-established life sciences innovation ecosystem as well. This ecosystem includes service support from specialized platforms, clustering of dedicated science parks, supportive services for technology and industry policies, major scientific infrastructure, and the empowerment of large-scale venture capital. A life sciences cluster can gradually accumulate competitive advantages with sustained growth of these conditions. This creates a significant challenge for emerging countries aiming to develop and catch up in life sciences.

The new era brings new opportunities, and the latest wave of scientific and industrial revolutions offers emerging countries a crucial chance to narrow the gap. Represented by Beijing's Zhongguancun Life Science Park, China's life science hubs have been advancing from foundational building and framework establishment to another phase of strong functionality. By creating an innovation ecosystem that tightly integrates policy, platforms, research, technology, and industry, life science hubs in China are set to make substantial contributions to the development of next-generation life sciences technologies, such as AI-driven drug discovery, synthetic biology, brain-computer interfaces, and gene editing.

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Appendix 1

Data source

Dimensions database: The Dimensions database is a comprehensive scientific information resource, encompassing real-time-updated sources of over 140 million publication records, 32 million datasets, 7.4 million research funding records, 160 million patent records, 900,000 clinical trial records, and 2.1 million policy document records. By flexibly integrating and linking various types of data, the Dimensions database effectively aids research institutions and scientists in conducting multidimensional research analysis. Researchers can perform studies on research themes, strengths in specific fields, research performance comparisons, and collaboration networks based on publications and citation analysis, while factoring in dimensions such as institutions, countries or regions, cities, and time. This enables them to map the trajectory of scientific development and provides comprehensive, objective, and robust scientific data support.

The Lens: A patent search platform that integrates academic and patent knowledge as a public resource, providing information for science and technology-driven problem-solving. The platform consolidates global patent and academic publication data. It offers comprehensive patent information and academic outcome analysis support for researchers, businesses, and policymakers with advanced search and analysis tools.

Nature Index: Compiled by the Springer Nature Group, this database measures high-level global scientific achievements by monitoring 145 high-quality journals in natural and health sciences. The journal selection is fully independent of the Nature Portfolio and is guided by recommendations from an independent expert panel, with input from a large-scale global survey of researchers to ensure a fair and consistent selection of top-tier journals. The Nature Index provides an objective metric for evaluating high-quality research output and collaboration worldwide, and it is one of the most authoritative and widely recognized indicators for assessing high-quality research at institutions and in regions.

AdisInsight database: The global drug R&D pipeline information monitoring database provides real-time information on drug R&D, disease treatment, and investment decisions. It helps researchers and investors understand the progress of drug development, identify the most promising research areas, assess potential R&D opportunities, and focus on the most promising development pathways.

Appendix 2

Data name and method of analysis

Life science hubs: The clusters selected in this report are studied and analyzed based on the metropolitan areas or major cities as their geographic boundary.

Active researchers: Researchers who have published at least one paper in a selected field within a selected time period.

Compound Annual Growth Rate (CAGR): The compound annual growth rate of the number of published papers, the number of scientists, or the frequency of paper citations over the selected period.

The field of life sciences: Based on the Dimensions database's FOR classification, it includes biomedical and clinical sciences, biological sciences, health sciences, psychology, environmental sciences and agricultural, veterinary, and food sciences. If a paper belongs to multiple disciplines, it will be only counted once.

Nature Index data: The paper data included in the Nature Index database for the most recent natural year. Researchers included in the Nature Index refer to those who have at least one paper indexed by Nature Index within the selected time period and field.

Total citation frequency of paper in patents, policies, and clinical trials: This refers to the total number of times a paper is cited in patents, policies, and clinical trials. Each citation will be counted in the statistics.

Frontier direction research activity: The activity is normalized based on the paper data for each frontier direction, and it is calculated as follows: The number of papers (Xi) in a particular frontier direction for the cluster is compared with the maximum value in the entire comparison cluster group, and then converted into a percentage form. The calculation formula is as follows:

Frontier direction research activity score = $\frac{X_i}{\max\limits_{1 \leq j \leq n} X_j} \times 100$

Note: The geographic boundaries for frontier direction research may slightly differ from those of other data sets.

Appendix 3

Data

Figure 1

Global drug R&D trend

	Research/Preclinical	Clinical	Regulatory	Marketed
2004	2716	1277	67	133
2005	2954	1377	70	137
2006	3198	1521	84	141
2007	3469	1717	80	158
2008	3654	1884	84	170
2009	3838	2023	85	176
2010	4058	2214	82	189
2011	4299	2438	97	208
2012	4463	2591	111	234
2013	4726	2807	111	264
2014	5017	3050	116	292
2015	5381	3346	131	348
2016	6364	3748	158	377
2017	6942	4153	174	417
2018	7659	4583	207	452
2019	8680	5007	226	491
2020	9938	5492	280	524
2021	11558	6098	287	563
2022	13173	6875	314	614
2023	14831	7586	349	646

Appendix

Table 2

		Number of active researchers					
No.	Innovation hub	2019	2020	2021	2022	2023	CAGR
1	Bay Area Innovative Health Hub	66461	72422	73981	76579	78739	4.33%
2	Seattle New Health Hub	23259	24993	26294	26564	28427	5.14%
3	Houston Medical Hub	26767	27982	27915	29079	30582	3.39%
4	Boston Medical Hub	78670	83766	87581	88390	93688	4.46%
5	Beijing Zhongguancun Life Science Park	279185	308395	350479	402466	432884	11.59%
6	Shanghai Zhangjiang Science City	109549	123327	142116	160163	171129	11.80%
7	Suzhou Industrial Park	13378	14916	18126	20742	23268	14.84%
8	Life Science Hub in San Diego	21424	22693	23502	23701	23669	2.52%
9	New York Life Science Hub	116786	127812	131504	132156	139047	4.46%
10	Washington Bio-health Hub	88704	94132	97480	97177	101595	3.45%
11	Los Angeles Life Science Hub	41220	44459	46694	46574	48110	3.94%
12	Pennsylvania Life Science Hub	38710	41568	42678	42942	45916	4.36%
13	London Life Science Hub	72213	79145	84508	80489	83958	3.84%
14	Ile-de-France Health Sciences Hub	72037	74935	76823	75725	74925	0.99%
15	Rotterdam Biopharmaceutical Hub	7144	7255	8065	8058	8112	3.23%
16	Milan Life science Hub	25457	28350	30023	31425	32687	6.45%
17	Geneva Healthcare Hub	19875	20970	21672	22355	24253	5.10%
18	Brussels Public Health Technology Hub	9359	10013	10656	10634	11217	4.63%
19	Singapore Biopharmaceutical Hub	26804	29813	30849	30975	32832	5.20%
20	Tokyo-Kobe Medical Industry Hub	174149	168825	172956	185452	189161	2.09%
21	Seoul Life and Healthcare Hub	84823	86534	90946	95233	100259	4.27%
22	Guwahati Biotechnology Park	32865	40896	50070	53892	58343	15.43%

		Number of scientists publishing papers in biological sciences and health sciences tracked by the Nature Index						Percentage of scientists publishing papers in biological sciences and health sciences tracked by the Nature Index				
No.	Innovation hub	2019	2020	2021	2022	2023	CAGR	2019	2020	2021	2022	2023
1	Bay Area Innovative Health Hub	5269	6398	6321	8139	6994	7.34%	7.93%	8.83%	8.54%	10.63%	8.88%
2	Seattle New Health Hub	1724	1824	1974	2795	2492	9.65%	7.41%	7.30%	7.51%	10.52%	8.77%
3	Houston Medical Hub	1830	2032	2243	2931	2738	10.60%	6.84%	7.26%	8.04%	10.08%	8.95%
4	Boston Medical Hub	6964	7944	8151	10890	10386	10.51%	8.85%	9.48%	9.31%	12.32%	11.09%
5	Beijing Zhongguancun Life Science Park	4286	5055	5274	6485	6771	12.11%	1.54%	1.64%	1.50%	1.61%	1.56%
6	Shanghai Zhangjiang Science City	2553	2762	3287	4788	4549	15.54%	2.33%	2.24%	2.31%	2.99%	2.66%
7	Suzhou Industrial Park	174	213	150	333	263	10.88%	1.30%	1.43%	0.83%	1.61%	1.13%
8	Life Science Hub in San Diego	2621	2616	2664	3003	2637	0.15%	12.23%	11.53%	11.34%	12.67%	11.14%
9	New York Life Science Hub	7225	8325	8587	11781	10884	10.79%	6.19%	6.51%	6.53%	8.91%	7.83%
10	Washington Bio-health Hub	5408	6203	6396	8657	7656	9.08%	6.10%	6.59%	6.56%	8.91%	7.54%
11	Los Angeles Life Science Hub	2234	2222	2425	3219	3021	7.84%	5.42%	5.00%	5.19%	6.91%	6.28%
12	Pennsylvania Life Science Hub	2056	2351	2518	3515	3306	12.61%	5.31%	5.66%	5.90%	8.19%	7.20%
13	London Life Science Hub	3250	4161	4380	6256	6319	18.08%	4.50%	5.26%	5.18%	7.77%	7.53%
14	Ile-de-France Health Sciences Hub	3061	3334	3436	5049	4411	9.56%	4.25%	4.45%	4.47%	6.67%	5.89%
15	Rotterdam Biopharmaceutical Hub	293	308	455	788	746	26.32%	4.10%	4.25%	5.64%	9.78%	9.20%
16	Milan Life science Hub	653	787	922	1368	1455	22.18%	2.57%	2.78%	3.07%	4.35%	4.45%
17	Geneva Healthcare Hub	1265	1271	1519	1789	1635	6.62%	6.36%	6.06%	7.01%	8.00%	6.74%
18	Brussels Public Health Technology Hub	216	313	233	506	388	15.77%	2.31%	3.13%	2.19%	4.76%	3.46%
19	Singapore Biopharmaceutical Hub	1092	1199	1174	1532	1232	3.06%	4.07%	4.02%	3.81%	4.95%	3.75%
20	Tokyo-Kobe Medical Industry Hub	3397	4162	4180	5309	4669	8.28%	1.95%	2.47%	2.42%	2.86%	2.47%
21	Seoul Life and Healthcare Hub	1211	1309	1171	2150	2258	16.85%	1.43%	1.51%	1.29%	2.26%	2.25%
22	Guwahati Biotechnology Park	171	147	353	374	256	10.61%	0.52%	0.36%	0.71%	0.69%	0.44%

Table 3

		Total number of papers in all fields (FOR first-level classification)						Number of papers in biological sciences and health sciences tracked by Nature Index	Proportion of papers in biological sciences and health sciences among total papers tracked by the Nature Index	Number of papers in biological sciences and health sciences tracked by Nature Index	Proportion of papers in biological sciences and health sciences among total papers tracked by the Nature Index	Number of papers in biological sciences and health sciences tracked by Nature Index	Proportion of papers in biological sciences and health sciences among total papers tracked by the Nature Index	Number of papers in biological sciences and health sciences tracked by Nature Index	Proportion of papers in biological sciences and health sciences among total papers tracked by the Nature Index	Number of papers in biological sciences and health sciences tracked by Nature Index	Proportion of papers in biological sciences and health sciences among total papers tracked by the Nature Index
No.	Hub	2019	2020	2021	2022	2023	CAGR (2019~2023)	2019	2019	2020	2020	2021	2021	2022	2022	2023	2023
1	Bay Area Innovative Health Hub	54088	60615	61278	60137	60286	2.75%	1731	3.20%	1872	3.09%	1805	2.95%	2588	4.30%	2333	3.87%
2	Seattle New Health Hub	21116	23614	23992	23516	23575	2.79%	609	2.88%	617	2.61%	690	2.88%	1057	4.49%	996	4.22%
3	Houston Medical Hub	22813	25306	25158	25519	25791	3.11%	539	2.36%	606	2.39%	591	2.35%	899	3.52%	917	3.56%
4	Boston Medical Hub	68780	77965	78864	76468	77795	3.13%	2153	3.13%	2275	2.92%	2266	2.87%	3415	4.47%	3245	4.17%
5	Beijing Zhongguancun Life Science Park	164985	183198	206264	235536	240966	9.93%	1114	0.68%	1267	0.69%	1417	0.69%	1735	0.74%	1865	0.77%
6	Shanghai Zhangjiang Science City	64469	74258	85177	95050	95973	10.46%	665	1.03%	718	0.97%	864	1.01%	1138	1.20%	1144	1.19%
7	Suzhou Industrial Park	8387	9517	11306	13387	14223	14.12%	70	0.83%	69	0.73%	66	0.58%	104	0.78%	99	0.70%
8	Life Science Hub in San Diego	18290	20381	20591	19641	19247	1.28%	901	4.93%	847	4.16%	873	4.24%	1015	5.17%	884	4.59%
9	New York Life Science Hub	97423	109264	110906	108560	110688	3.24%	2434	2.50%	2589	2.37%	2713	2.45%	3849	3.55%	3511	3.17%
10	Washington Bio-health Hub	75268	83353	83682	80620	80304	1.63%	1844	2.45%	2018	2.42%	1953	2.33%	2880	3.57%	2618	3.26%
11	Los Angeles Life Science Hub	37126	41529	42720	41744	41927	3.09%	755	2.03%	831	2.00%	842	1.97%	1383	3.31%	1223	2.92%
12	Pennsylvania Life Science Hub	33553	38005	38529	37462	37942	3.12%	746	2.22%	737	1.94%	789	2.05%	1258	3.36%	1138	3.00%
13	London Life Science Hub	69169	78133	83706	77252	76920	2.69%	1105	1.60%	1247	1.60%	1330	1.59%	2169	2.81%	1982	2.58%
14	Ile-de-France Health Sciences Hub	52052	56389	57034	54136	53658	0.76%	928	1.78%	967	1.71%	963	1.69%	1373	2.54%	1299	2.42%
15	Rotterdam Biopharmaceutical Hub	7497	7981	8388	8420	8241	2.39%	131	1.75%	118	1.48%	144	1.72%	327	3.88%	317	3.85%
16	Milan Life science Hub	24481	29870	31303	31402	32102	7.01%	178	0.73%	220	0.74%	260	0.83%	465	1.48%	491	1.53%
17	Geneva Healthcare Hub	17879	19938	20614	20304	20643	3.66%	469	2.62%	498	2.50%	549	2.66%	704	3.47%	625	3.03%
18	Brussels Public Health Technology Hub	8777	10002	10566	10335	10706	5.09%	98	1.12%	134	1.34%	115	1.09%	217	2.10%	202	1.89%
19	Singapore Biopharmaceutical Hub	23337	26443	27252	27313	28040	4.70%	295	1.26%	317	1.20%	324	1.19%	460	1.68%	423	1.51%
20	Tokyo-Kobe Medical Industry Hub	106243	112678	117009	113715	112552	1.45%	1088	1.02%	1250	1.11%	1266	1.08%	1602	1.41%	1485	1.32%
21	Seoul Life and Healthcare Hub	58925	62881	65885	66187	66968	3.25%	304	0.52%	345	0.55%	326	0.49%	582	0.88%	582	0.87%
22	Guwahati Biotechnology Park	25109	33856	41690	44448	47298	17.15%	52	0.21%	39	0.12%	67	0.16%	110	0.25%	92	0.19%

Appendix

Table 3

		The number of papers in the field of life sciences						Proportion of papers in the field of life sciences					
No.	Hub	2019	2020	2021	2022	2023	CAGR (2019~2023)	2019	2020	2021	2022	2023	CAGR (2019~2023)
1	Bay Area Innovative Health Hub	32532	37621	37884	37811	37701	3.76%	60.15%	62.07%	61.82%	62.87%	62.54%	0.98%
2	Seattle New Health Hub	15101	17303	17291	17058	16947	2.93%	71.51%	73.27%	72.07%	72.54%	71.89%	0.13%
3	Houston Medical Hub	17464	19775	19692	20029	20276	3.80%	76.55%	78.14%	78.27%	78.49%	78.62%	0.67%
4	Boston Medical Hub	47797	55690	56143	54735	55141	3.64%	69.49%	71.43%	71.19%	71.58%	70.88%	0.50%
5	Beijing Zhongguancun Life Science Park	52740	64956	72075	78908	74165	8.90%	31.97%	35.46%	34.94%	33.50%	30.78%	-0.94%
6	Shanghai Zhangjiang Science City	24333	30596	34038	37124	35120	9.61%	37.74%	41.20%	39.96%	39.06%	36.59%	-0.77%
7	Suzhou Industrial Park	3417	4235	4833	5499	5554	12.91%	40.74%	44.50%	42.75%	41.08%	39.05%	-1.05%
8	Life Science Hub in San Diego	12565	14425	14242	13593	13214	1.27%	68.70%	70.78%	69.17%	69.21%	68.65%	-0.02%
9	New York Life Science Hub	66879	77384	77880	76698	78159	3.97%	68.65%	70.82%	70.22%	70.65%	70.61%	0.71%
10	Washington Bio-health Hub	50152	56683	56993	54851	54264	1.99%	66.63%	68.00%	68.11%	68.04%	67.57%	0.35%
11	Los Angeles Life Science Hub	21982	25741	26508	26092	26527	4.81%	59.21%	61.98%	62.05%	62.50%	63.27%	1.67%
12	Pennsylvania Life Science Hub	24893	28749	28897	28313	28713	3.63%	74.19%	75.65%	75.00%	75.58%	75.68%	0.50%
13	London Life Science Hub	45133	52102	56107	50853	49749	2.46%	65.25%	66.68%	67.03%	65.83%	64.68%	-0.22%
14	Ile-de-France Health Sciences Hub	27475	30682	30536	29123	28293	0.74%	52.78%	54.41%	53.54%	53.80%	52.73%	-0.03%
15	Rotterdam Biopharmaceutical Hub	6276	6659	7025	7027	6915	2.45%	83.71%	83.44%	83.75%	83.46%	83.91%	0.06%
16	Milan Life science Hub	15772	20475	21262	20909	20913	7.31%	64.43%	68.55%	67.92%	66.58%	65.15%	0.28%
17	Geneva Healthcare Hub	10001	11588	12203	12008	11800	4.22%	55.94%	58.12%	59.20%	59.14%	57.16%	0.54%
18	Brussels Public Health Technology Hub	5173	6174	6438	6400	6490	5.83%	58.94%	61.73%	60.93%	61.93%	60.62%	0.71%
19	Singapore Biopharmaceutical Hub	9018	11138	11417	10911	10722	4.42%	38.64%	42.12%	41.89%	39.95%	38.24%	-0.26%
20	Tokyo-Kobe Medical Industry Hub	49849	56009	59719	57257	55205	2.58%	46.92%	49.71%	51.04%	50.35%	49.05%	1.12%
21	Seoul Life and Healthcare Hub	30088	32166	32955	32857	32394	1.86%	51.06%	51.15%	50.02%	49.64%	48.37%	-1.34%
22	Guwahati Biotechnology Park	12058	17381	20600	21503	22728	17.17%	48.02%	51.34%	49.41%	48.38%	48.05%	0.02%

Appendix

Table 3

		Number of internationally co-authored papers in biological sciences and health sciences tracked by Nature Index						Proportion of internationally co-authored papers in biological sciences and health sciences tracked by the Nature Index					
No.	Hub	2019	2020	2021	2022	2023	CAGR (2019~2023)	2019	2020	2021	2022	2023	CAGR (2019~2023)
1	Bay Area Innovative Health Hub	896	971	966	1357	1298	9.71%	51.76%	51.87%	53.52%	52.43%	55.64%	1.82%
2	Seattle New Health Hub	344	342	406	572	530	11.41%	56.49%	55.43%	58.84%	54.12%	53.21%	-1.48%
3	Houston Medical Hub	314	357	320	481	518	13.33%	58.26%	58.91%	54.15%	53.50%	56.49%	-0.77%
4	Boston Medical Hub	1164	1304	1340	1898	1896	12.97%	54.06%	57.32%	59.14%	55.58%	58.43%	1.96%
5	Beijing Zhongguancun Life Science Park	679	742	786	863	920	7.89%	60.95%	58.56%	55.47%	49.74%	49.33%	-5.15%
6	Shanghai Zhangjiang Science City	430	464	514	582	566	7.11%	64.66%	64.62%	59.49%	51.14%	49.48%	-6.47%
7	Suzhou Industrial Park	52	49	40	57	54	0.95%	74.29%	71.01%	60.61%	54.81%	54.55%	-7.43%
8	Life Science Hub in San Diego	532	487	501	567	507	-1.20%	59.05%	57.50%	57.39%	55.86%	57.35%	-0.72%
9	New York Life Science Hub	1303	1459	1536	2142	1969	10.87%	53.53%	56.35%	56.62%	55.65%	56.08%	1.17%
10	Washington Bio-health Hub	944	1096	1080	1491	1346	9.27%	51.19%	54.31%	55.30%	51.77%	51.41%	0.11%
11	Los Angeles Life Science Hub	422	489	484	751	693	13.20%	55.89%	58.84%	57.48%	54.30%	56.66%	0.34%
12	Pennsylvania Life Science Hub	382	398	411	643	573	10.67%	51.21%	54.00%	52.09%	51.11%	50.35%	-0.42%
13	London Life Science Hub	926	1041	1116	1789	1663	15.76%	83.80%	83.48%	83.91%	82.48%	83.91%	0.03%
14	Ile-de-France Health Sciences Hub	760	785	790	1081	1038	8.11%	81.90%	81.18%	82.04%	78.73%	79.91%	-0.61%
15	Rotterdam Biopharmaceutical Hub	120	98	119	273	247	19.78%	91.60%	83.05%	82.64%	83.49%	77.92%	-3.96%
16	Milan Life science Hub	158	192	229	397	412	27.07%	88.76%	87.27%	88.08%	85.38%	83.91%	-1.40%
17	Geneva Healthcare Hub	377	400	478	591	528	8.79%	80.38%	80.32%	87.07%	83.95%	84.48%	1.25%
18	Brussels Public Health Technology Hub	88	125	107	201	179	19.42%	89.80%	93.28%	93.04%	92.63%	88.61%	-0.33%
19	Singapore Biopharmaceutical Hub	252	281	285	406	391	11.61%	85.42%	88.64%	87.96%	88.26%	92.43%	1.99%
20	Tokyo-Kobe Medical Industry Hub	674	756	771	967	861	6.31%	61.95%	60.48%	60.90%	60.36%	57.98%	-1.64%
21	Seoul Life and Healthcare Hub	202	240	228	378	361	15.62%	66.45%	69.57%	69.94%	64.95%	62.03%	-1.71%
22	Guwahati Biotechnology Park	37	26	38	75	69	16.86%	71.15%	66.67%	56.72%	68.18%	75.00%	1.32%

Table 4

		Number of patents						Total citations from patents, policy reports and clinical trials (2019-2023)			Total citations of clinical trials in papers					
No.	Hub	2019	2020	2021	2022	2023	CAGR(%)	Number of papers (regardless of subject area)	Total citations from patents, policy reports and clinical trials	Average citation rate	2019	2020	2021	2022	2023	CAGR(%)
1	Bay Area Innovative Health Hub	37992	37239	35443	32980	35280	-1.83%	303137	39698	0.131	482	470	443	398	388	-5.28%
2	Seattle New Health Hub	9744	9160	7985	6814	6904	-8.25%	118463	17826	0.150	249	275	240	240	259	0.99%
3	Houston Medical Hub	4413	3587	3645	3214	3078	-8.61%	126921	10108	0.080	402	419	347	380	386	-1.01%
4	Boston Medical Hub	9653	9715	9330	8484	8951	-1.87%	388038	52666	0.136	553	552	524	456	430	-6.10%
5	Beijing Zhongguancun Life Science Park	89821	108945	132995	142786	134205	10.56%	1040123	63303	0.061	136	181	174	185	190	8.72%
6	Shanghai Zhangjiang Science City	16376	19579	25239	24206	21511	7.06%	417710	25247	0.060	100	131	105	143	183	16.31%
7	Suzhou Industrial Park	2578	3049	3711	3539	3341	6.70%	57116	3280	0.057	12	13	23	20	27	22.47%
8	Life Science Hub in San Diego	9153	8445	8439	7746	10864	4.38%	100118	11983	0.120	192	188	170	130	154	-5.36%
9	New York Life Science Hub	29268	29401	28320	22832	23127	-5.72%	550489	54822	0.100	1048	1059	1010	861	865	-4.68%
10	Washington Bio-health Hub	5084	4913	4722	4420	4442	-3.32%	412869	50674	0.123	709	723	666	623	594	-4.33%
11	Los Angeles Life Science Hub	2393	2477	2542	2552	2949	5.36%	209818	17700	0.084	483	495	466	427	470	-0.68%
12	Pennsylvania Life Science Hub	4102	3807	3752	3631	3769	-2.09%	190033	15592	0.082	348	399	331	299	281	-5.21%
13	London Life Science Hub	3613	3541	3286	2893	2880	-5.51%	393019	47899	0.122	330	354	283	321	291	-3.10%
14	Ile-de-France Health Sciences Hub	16977	16714	16611	14548	14307	-4.19%	292564	21412	0.073	273	333	304	284	256	-1.59%
15	Rotterdam Biopharmaceutical Hub	305	259	137	14548	126	-19.83%	41377	4370	0.106	55	56	44	49	45	-4.89%
16	Milan Life science Hub	1019	1105	1118	1058	1183	3.80%	151811	11092	0.073	153	195	173	164	173	3.12%
17	Geneva Healthcare Hub	1821	1962	2013	1991	2168	4.46%	102646	17034	0.166	50	47	42	61	39	-6.02%
18	Brussels Public Health Technology Hub	473	437	414	361	352	-7.12%	51842	5055	0.098	107	127	109	98	88	-4.77%
19	Singapore Biopharmaceutical Hub	1750	1471	1377	1408	1558	-2.86%	134215	11732	0.087	45	61	47	39	34	-6.77%
20	Tokyo-Kobe Medical Industry Hub	166382	162428	157361	162863	160225	-0.94%	680478	22314	0.033	234	258	220	220	219	-1.64%
21	Seoul Life and Healthcare Hub	37209	37148	37750	36556	41509	2.77%	327471	20784	0.063	180	187	185	154	179	-0.14%
22	Guwahati Biotechnology Park	621	879	1207	1083	1793	30.35%	196374	7065	0.036	20	27	21	15	15	-6.94%

Table 5

		Number of papers in life sciences frontier areas (2019-2023)					Research activity score in life sciences frontier areas (2019-2023)				
No.	Hub	Synthetic biology	Brain science	Phenomics	Computational biology	Gene and cell therapy	Synthetic biology	Brain science	Phenomics	Computational biology	Gene and cell therapy
1	Bay Area Innovative Health Hub	513	25,335	225	1,351	4,330	12	24	20	30	34
2	Seattle New Health Hub	597	20,889	192	1,043	3,858	14	20	17	23	31
3	Houston Medical Hub	482	28,567	197	1,254	6,275	11	27	18	28	50
4	Boston Medical Hub	2347	78,824	674	4,187	11,691	53	74	61	92	93
5	Beijing Zhongguancun Life Science Park	4408	106,231	1,106	4,172	12,638	100	100	100	92	100
6	Shanghai Zhangjiang Science City	2142	59,501	543	2,398	10,133	49	56	49	53	80
7	Suzhou Industrial Park	199	9,720	33	306	2,155	5	9	3	7	17
8	Life Science Hub in San Diego	662	22,093	252	841	2,606	15	21	23	18	21
9	New York Life Science Hub	815	62,991	506	3,192	9,538	18	59	46	70	75
10	Washington Bio-health Hub	740	47,080	403	2,183	5,757	17	44	36	48	46
11	Los Angeles Life Science Hub	442	32,729	201	1,514	4,473	10	31	18	33	35
12	Pennsylvania Life Science Hub	385	34,656	384	1,446	6,259	9	33	35	32	50
13	London Life Science Hub	1591	79,755	701	4,555	10,239	36	75	63	100	81
14	Ile-de-France Health Sciences Hub	940	39,005	466	1,565	5,949	21	37	42	34	47
15	Rotterdam Biopharmaceutical Hub	44	9,985	100	501	1,306	1	9	9	11	10
16	Milan Life science Hub	247	29,703	162	1,587	5,000	6	28	15	35	40
17	Geneva Healthcare Hub	446	17,295	150	896	1,873	10	16	14	20	15
18	Brussels Public Health Technology Hub	143	9,234	49	509	1,240	3	9	4	11	10
19	Singapore Biopharmaceutical Hub	826	19,158	159	1,479	2,877	19	18	14	32	23
20	Tokyo-Kobe Medical Industry Hub	1,343	64,685	384	2,312	8,005	30	61	35	51	63
21	Seoul Life and Healthcare Hub	788	47,411	196	2,265	5,382	18	45	18	50	43
22	Guwahati Biotechnology Park	662	20,906	422	1,387	2,461	15	20	38	30	19

Table 6

No.	Frontier fields of life sciences	Global number of papers (2014-2023) 2014	2015	2016	2017	2018
1	Synthetic biology	5942	7662	7771	7893	10211
2	Brain science	381021	390622	421457	463848	493940
3	Phenomics	1074	1261	1872	1803	2487
4	Computational biology	1075	1124	1297	1873	3639
5	Gene and cell therapy	39463	40455	46496	45136	52583

No.	Frontier fields of life sciences	2019	2020	2021	2022	2023	CAGR(%) 2014-2023
1	Synthetic biology	11141	12149	14213	15074	17169	12.51%
2	Brain science	521654	595582	651415	666886	672089	6.51%
3	Phenomics	2616	3312	4381	4736	5028	18.71%
4	Computational biology	6849	12461	19961	28866	43241	50.76%
5	Gene and cell therapy	49933	62350	75821	75620	77331	7.76%

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