Abstract: Based on the logistic growth model, the relationship between technology innovation and the evolution of economic forms was analyzed, and the main characteristics and basic laws of the five economic forms of hunter–gatherer, agriculture, industry, information, and bioeconomy were summarized. Based on a comprehensive and intensive scan of the latest bioeconomy development strategies of various countries, we summarized their two main driving forces from the technological supply side and economic and social demand side, as well as their four distinctive features, namely the comprehensiveness of science and technology innovation, the aggregation of industrial development, the globalization of development goals, and strong policy dependence. Finally, we proposed countermeasures to design the implementation path of the bioeconomy and improve the quality of the bioeconomy factor supply in terms of the development and application of biotechnology, the upgradation of bioindustry clusters, the positive policy environment, and the theorization of the bioeconomy.

Keywords: technology innovation; driving forces; development path; economic form succession

1. Introduction

Since the 1970s, research on recombinant DNA and the monoclonal antibody has promoted the rapid evolution of modern biotechnology. As early as the turn of the millennium, it was proposed that the 21st century would be the century of biology [1]. With the increasingly abundant application scenarios of biotechnology, the economic attributes of biotechnology have been tapped and strengthened, and the industries and industrial clusters of bioenergy, biomedicine, and so on have been gradually established across the world. The progress of biotechnology has triggered new modes of production, circulation, exchange, and consumption, as well as institutional systems, which have greatly changed the economic and social structure and given rise to a new economic form of bioeconomy, on the basis of the agricultural economy, industrial economy, and information economy. The bioeconomy is a new form of economy that is different from the industrial economy and the information economy; it is also a complex form of economy that links the industrial chains of various industries, in terms of both productivity and production relations [2,3].

Compared to the agricultural economy and the industrial economy, the definition of the bioeconomy is very broad, even vague. In 1998, one of the earliest understandings or interpretations of the modern concept of the bioeconomy was proposed by Juan Enriquez, an American entrepreneur. It was declared that new discoveries and applications related to genomics would initiate the molecular and genetic revolution, which would lead to the reorganization and integration of medicine, health, agriculture, food, nutrition, energy, the environment, and other industries and then bring profound changes in the
world economy [4]. In 2005, the European Union introduced the “Knowledge-Based-Bio-Economy” (KBBE) [5] for the first time, initiating a global boom in the development of the bioeconomy, which has led to the rapid development of the concept of the bioeconomy along with practical activities and thus the expansion of its scale and consistency [6]. So far, more than 60 countries and regions have issued special strategies or action plans, and the bioeconomy has gradually entered a “mature period” [7]. In the past two decades of implementation, the bioeconomy has proven to be a more sustainable business model and economic form. Through the breakthrough and application of biorefining, gene editing, synthetic biology, and other technologies, the absolute amount of fossil energy use can be reduced on the input side, while environmental pollution and greenhouse gas emissions can be reduced on the output side [8–11]. China’s bioeconomic practice started relatively late, mainly focusing on biotechnology innovation and the development of the bioindustry in the early stage. After the 18th National Congress of the Communist Party of China, great progress was made, the scale of the bioindustry continued to expand, and its structure and function became more and more reasonable. Recently, the publication of the “14th Five-Year Plan for Bioeconomy Development” ensured the bioeconomy as an important national development strategy.

Every economic form has a country in the leading and core position. In the era of the agricultural economy, China’s agricultural technology and organizational methods are more advanced, and the total economic output once accounted for more than 20% of the total world economy for a long time [12]. Then, the UK, which took the lead in completing the industrial revolution, quickly replaced China as the center of the industrial economy era. In the 1970s, the United States seized the commanding heights of the information economy and gradually occupied the dominant position in the world economy. At present, the most unprecedented changes in a hundred years and the superposition of the COVID-19 pandemic make the bioeconomy an effective means to achieve sustainable development under the constraints of resources and the environment and further highlight its economic, social, and environmental benefits. It is of great significance to seize the opportunity of the new round of scientific and technological revolution and industrial transformation and vigorously enhance the competitiveness of the economy.

With the development of the global bioeconomy, an increasing number of researchers deconstruct and analyze the phenomena in economic and social development through empirical means. Scholars in different fields explain and describe the formation mechanisms and characteristics of the bioeconomy from their perspectives. Within this, the important role of biotechnology is deeply analyzed [13], and the evaluation of the social and environmental benefits brought by the application of biotechnology have also become a research hot spot [14,15]. So far, the bioeconomy has been proven to have significant economic, social, and environmental benefits, including increasing employment, reducing pollution emissions, etc., in countries and regions such as the United States, the European Union, and Germany [16,17]. In addition, the input–output model, the econometric model, and the computable general equilibrium model are widely used to evaluate the implementation effect of bio-economic policies [18]. The aim of this study is to deepen our understanding of the characteristics, patterns, and operation rules of the bioeconomy and to provide insights for the further spread of the bioeconomy to China and other countries. With these in mind, the aim of this paper is to deepen our understanding of the driving force and pathways of the bioeconomy development based on the literature review and the comparative analysis of the latest national bioeconomy strategies. The review included a screening of the abstracts of 120 papers, from which 83 papers were considered relevant to the analysis after a discretionary selection. After the comprehensive exploration of the characteristics, patterns, and operation rules of the bioeconomy, the paper provides insights in terms of biotechnology innovation and the policy environment for the further spread of the bioeconomy to China and other countries.
2. Technological Development and Economic Form Succession

Economic form refers to the external manifestation of the production mode, which is determined by and reflects the technical mode, which shows the essential characteristics of the whole economic system or economic structure. The starting point of the formation of each economic form is the birth of new technology, and the process of its formation depends on the degree and speed at which the new technology is accepted by production. The technical basis and technical differences of the production methods bring about differences in economic systems or economic structures and shape the regularity and development characteristics of different economic forms. Throughout human history, driven by three scientific and technological revolutions, economic development has gone through five stages: hunter and gatherer economy, agriculture economy, industry economy, information economy, and bioeconomy (Figure 1) [19–21]. Each economic form is divided into gestation, rapid development, maturity, and decline periods, along with the life cycle of the dominant technology. On the premise of generally following the development law of the logistic growth model curve, it shows distinct characteristics and forms its own operating rules (Table 1).

![Figure 1. Evolution of the five economic forms, developed by the authors.](image)

Since the appearance of human beings about 5 million years ago, humans have mainly made a living by hunting and gathering, relying on their physical strength as the dominant means of production and some simple tools that appeared later as supplements. The production activities had to depend on nature to a large extent and showed the original “harmony between man and nature” relationship in the hunting and gathering stage (Table 1) and with no obviously leading technology at this stage.

Around 10,000 BC, with the development of crop planting and livestock and poultry breeding, land became the main means of labor, together with agricultural tools such as bronze and iron tools, and human society entered the agricultural economy [22,23]; with the progress of irrigation, pesticide and fertilizer application, and breeding technology, the intelligence factor of the labor force has become the driving force for the development of traditional agriculture to modern agriculture. In this process, the yield obtained by adding labor and capital to the land will increase but will stop increasing at a certain amount and will reflect the law of “diminishing returns” until new technological breakthroughs or other changes in the production conditions (Table 1).
Table 1. Characteristics and basic laws of the main economic forms, developed by the authors.

<table>
<thead>
<tr>
<th>Economic Form</th>
<th>Dominant Technologies</th>
<th>Key Features</th>
<th>Basic Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hunter–gatherer Economy</td>
<td>Application of stone tools</td>
<td>Labor + simple tools</td>
<td>Unity of heaven and man</td>
</tr>
<tr>
<td>Agriculture Economy</td>
<td>Use of agricultural tools; Irrigation, fertilizer use; breeding techniques</td>
<td>Land + farming tools (+intelligence)</td>
<td>Law of diminishing returns on land</td>
</tr>
<tr>
<td>Industry Economy</td>
<td>Steam engine use; Mechanized equipment</td>
<td>The law of increasing value of scale</td>
<td>The law of surplus value</td>
</tr>
<tr>
<td>Information Economy</td>
<td>Electronic science, communication technology, internet technology</td>
<td>Artificial intelligence + capital</td>
<td>Moore’s Law; Winner takes all</td>
</tr>
<tr>
<td>Bioeconomy</td>
<td>Sequencing technology, transgenic and gene editing technology, synthetic biology</td>
<td>Biological resources + biotechnology + capital</td>
<td>Beyond the laws of nature; The new “Celestial Harmony”</td>
</tr>
</tbody>
</table>

At the end of the 18th century, major developed countries completed the industrial revolution; thus, power machines replaced manual work on a large scale (Table 1) [24,25]. In this period, standardized and batch production continued to reduce enterprise costs sharply, and the economic benefits of enterprises increased due to the expansion of the production scale. Under the industrial economy, the possession and allocation of natural resources such as fossil fuels played a supportive role in the development of machine production and thus became the decisive factor of the economic development level. At the same time, the role of capital elements is becoming more and more important. Labor and capital surplus value are the essence of industrial economic production [26]. With the increasing influence of energy and resource constraints, information has become the main force of economic development.

Since the 1970s, large-scale computers, microprocessors, and the internet have appeared one after another and become widely popular. The leap-forward development of electronic technology and communication technology has widely confirmed Moore’s Law, from memory chips to the whole information field [27]. As a form of knowledge, information improves the degree of automation of material production departments and promotes the development of the information service industry through the information superhighway, such as the network [28]. With the support of capital, the progress of information technology is amazing, and artificial intelligence has been greatly strengthened and may even replace human mental work; thus, the labor force factor has been hidden by the higher artificial intelligence [29–32]. Another characteristic of the information economy is that a breakthrough in a certain aspect will lead to accumulated advantages, and more opportunities for success and progress will be obtained through constant positive feedback, which is reflected in the “winner takes all”.

The bioeconomy started slightly later than the information economy, but it is developing faster than the other economic forms. By the year 2000, when the human genome map was drawn, the application scenarios of biotechnology became more and more extensive, and the bioeconomy gradually developed and matured. Currently, many countries around the world have entered the maturity of the knowledge economy and are in transition to the bioeconomy, accelerated by the national policy framework [33]. Based on renewable biological resources, the bioeconomy provides biological products through intensive capital investment and the advancement of the biotechnology it brings. Modern biotechnology, represented by genetic modification, gene editing, synthetic biology, etc., helps to replace natural variation and hybrid selection and breeding, greatly shortening the process of improvement in plant, animal, and microbial varieties and gradually reflecting the results of innovation beyond the laws of nature. Adopting biotechnology (bio-process and biorefinery technology) to produce biochemicals, biomaterials, and bioenergy fundamentally
reduces the dependence on fossil-based raw materials and energy. At the same time, the creation of new varieties with high quality and high yield through biotechnology has reduced the dependence of traditional agriculture on land, climate, and other resources, improved the sustainability of agriculture and industry, and demonstrated a new harmonious relationship between man and nature (Table 1).

3. The Dynamics and Characteristics of Biotechnology to Bioeconomy

Throughout the history of world economic development, only in the wave of large-scale scientific and technological revolution does a certain kind of technology continue to mature and become the dominant mode of production technology; the industries and industrial clusters based on this technology gradually form a scale, and this economic form is truly established by triggering industrial revolution and changing people’s production mode and social mode. In recent years, biotechnology, as one of the rapidly developing high-tech fields, has drawn the high attention of governments, scientific communities, and enterprises all over the world with its attractive prospects [34,35]. Driven by the explosive development of life sciences and the demand of the global society for a more sustainable development model, the bioeconomy gradually develops and flourishes through the practice of leading and supporting related industries, such as grain production, energy supply, nutrition, and health in various countries, and then, it shows the theoretical characteristics of the evolution from an economic and social activity that shapes the future to a scientific one that predicts the future (Table 2).

Table 2. National bioeconomy development strategies and their leading biotechnologies.

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Characteristics of Leading Biotechnology</th>
<th>Development Status and Trend</th>
<th>Policy Documents</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>Focus on food, feed, forest, and fibers; the 4Fs)</td>
<td>In 2021, the concept of “bio-economy” was expressed as “circular-bio-based-economy”, which highlighted the goal of “sustainable development”</td>
<td>Conference: the knowledge-based bio-economy, 2005; Innovating for Sustainable Growth: A Bio-economy for Europe, 2012; A sustainable bio-economy for Europe: strengthening the connection between economy, society, and the environment, 2018; Foresight scenarios for the EU bio-economy in 2050, 2021</td>
<td>[5,36–38]</td>
</tr>
<tr>
<td>US</td>
<td>Mainly relying on bio-based products and bioenergy development technology to promote the early development of the bioeconomy</td>
<td>The application scenarios of biotechnology are gradually extended to the fields of health, bio-medicine, and safety; in the future, the development focus will be on personalized medical care, energy production based on biomanufacturing technology, and environmental remediation with biotechnology.</td>
<td>Executive order: Developing and promoting bio-based products and bio-energy, 1999; National Bio-economy Blueprint, 2012; The Biomass Research and Development Board. Bio-economy initiative implementation framework, 2019; Bio-economy research and development act of 2020, 2020</td>
<td>[39–42]</td>
</tr>
</tbody>
</table>
Table 2. Cont.

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Characteristics of Leading Biotechnology</th>
<th>Development Status and Trend</th>
<th>Policy Documents</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>The private sector promotes R &amp; D and rapid application of industrial biotechnology</td>
<td>Gradually covering the agricultural economy and all manufacturing sectors as well as the related service areas of development, production, processing, and treatment or utilization of any form of biological resources (such as plants, animals, and microorganisms); this year, we put forward five action areas: ensuring global nutrition supply, ensuring sustainable agricultural production, producing healthy and safe food, using renewable resources in the industry, and developing biomass-based energy carriers.</td>
<td>National Research Strategy Bio-economy 2030, 2019; National Bio-economy Strategy 2020, 2020</td>
<td>[43,44]</td>
</tr>
</tbody>
</table>

3.1. National Bio-Economic Development Path

3.1.1. EU

The EU has been playing a vanguard role in shaping and promoting the bioeconomy of the European Union. In its conference report: The Knowledge-based bioeconomy, published in 2005, it put forward the hope of supporting a future society that is no longer completely dependent on fossil energy in terms of energy and industrial raw materials by transforming life science knowledge into new, sustainable, eco-efficient, and competitive products.

Innovating for Sustainable Growth: A bioeconomy for Europe, published in 2012, proposed that the EU bioeconomy include agriculture, forestry, fishery, food, pulp, and paper industries, as well as some industries of chemicals and biotechnology and energy industries, which are the key elements to realizing intelligent and green growth in Europe. In terms of technology, biotechnology in the early European Union focused on four aspects: food, feed, forest, and fibers (4Fs), and relied on the common progress and cross-integration of life science, agronomy, ecology, food science, biotechnology, nanotechnology, information communication technology (ICT), and engineering. Research and innovation in the EU bioeconomy have significantly improved the management of its renewable bio-resources and opened up new and diversified markets for food and bio-based products [47]. They
have also brought social and environmental benefits, including the creation of jobs, the improvement of the environmental sustainability of the primary production and processing industries, the reduction of the dependence on fossil fuels, and the reduction of greenhouse gas emissions [48]. In 2016, the European Union released the report *A Sustainable bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment*. According to the evaluation and calculation of the Joint Research Center (JRC) of the European Commission in 2015, the bioeconomy in 28 EU countries generated a turnover of about EUR 2.3 trillion, an increase of 5% over the previous year; more than 18 million people are employed, of which the employment driven by agriculture and food manufacturing accounts for 76% of the whole bioeconomic industry [49]. Within the EU, the bioeconomy of different countries has different development characteristics. For example, the bioeconomy of Finland, Sweden, Estonia, and Latvia is mainly oriented to the forest sector; in Italy and Portugal, 14% and 16% of the bioeconomic added value come from the manufacture of bio-based textiles, respectively; 36% of the bioeconomic added value in Ireland and 35% in Denmark comes from the manufacture of bio-based chemicals, medicines, plastics, and rubber.

In 2018, the European Union released an upgraded version of its bioeconomic strategy, which put forward three key objectives: accelerating the development of the bioindustry, promoting the bioeconomic agenda of member countries and urban and rural areas, and protecting ecosystems. Through 14 specific tasks, it further strengthened the link between the circular and sustainable bioeconomy and the society and environment and emphasized the role of the bioeconomy in meeting global challenges, such as achieving the Sustainable Development Goals (SDG) set by the United Nations and the climate targets of the Paris Agreement.

In 2021, the European Union released the report *Foresight Scenarios for the EU Bioeconomy in 2050: Future Transition for the Bioeconomy towards Sustainable Development and a Climate-neutral Economy*. By constructing a scenario prediction model based on policy effectiveness and social attitude, it described the development scenario of the bioeconomy in Europe and even the whole world in 2050 from the perspectives of the supply side and the demand side. The report pointed out that the bioeconomy must aim at sustainable development and climate neutrality and improve its inclusiveness in the economic and social realities of the member countries and, at the same time, that it needs to expand its cooperative relationship with other countries outside the EU.

### 3.1.2. The United States

At the beginning of the 21st century, the US bioeconomy focused on the development and utilization of bio-based products and bioenergy, and its related fields were mainly agriculture and energy. Its development path is to enable renewable agricultural and forestry resources to become a major source of electricity, fuels, chemicals, pharmaceuticals, and other materials, through innovation and the application of bio-based products and bioenergy technologies, with new jobs, markets, and economic opportunities created in rural areas through [50,51]. In the early stage of development, the combination of bioenergy and biofuel, including starch-based ethanol and soybean oil and the development of biorefining, significantly reduced the dependence of the United States on foreign oil, improved air quality, and reduced greenhouse gas emissions. Therefore, in 1999, the U.S. federal government established a series of specialized agencies, including the Interagency Council on Bio-based Products and Bio-energy, the Advisory Committee on Bio-based Products and Bio-energy, the Working Group on Bio-based Products and Bio-energy, the Working Group on Bio-based Products and Bio-based Activities in the Departments of Agriculture and Energy, and the National Coordination Office for Bio-based Products and Bio-energy.

In recent years, with the progress of life science and biotechnology, the U.S. bioeconomy has developed vigorously. In *National bioeconomy Blueprint*, published in 2012, the bioeconomy was defined as an economic activity driven by the research and innovation of bioscience. Nowadays, the US bioeconomy is mainly based on the development of genetic
engineering, DNA sequencing, and high-throughput automatic biological sample processing, which promotes the development of biotechnology in the biomedical, agricultural, and industrial fields and even in the biosecurity area [52]. In 2019, the U.S. bioeconomy Initiative Implementation Framework proposed that the United States would further strengthen financial support and broaden financing channels, focusing on supporting technological innovations, such as the algae fuel system, gene editing, biotransformation, the carbon cycle, etc., to promote economic growth, ensure energy security, and improve environmental quality. The future bioeconomy of the United States depends on the expansion of emerging technologies, including synthetic biology (direct engineering of microorganisms and plants), protein omics (large-scale research and operation of protein in organisms), and bioinformatics (computational tools for expanding the use of biology and related data). Technological progress has brought a series of emerging trends to different fields, and it will be reflected in the health field represented by personalized medicine, the energy production field based on bio-manufacturing technology, the agricultural field, and the environmental protection field using biotechnology to repair the environment.

In 2022, Schmidt Futures, a philanthropic initiative, released The U.S. Bioeconomy: Charting a Course for a Resilient and Competitive Future [53], pointing out that the integration of platform technologies such as artificial intelligence and synthetic biology can accelerate the formulation of biotechnology solutions in many economic fields and push the US economy towards a resilient and sustainable zero-carbon model. The report puts forward the development goal of a “4 trillion global bioeconomy”, in which the goal of the United States is to maintain competitiveness and international leadership. Therefore, it is necessary to vigorously support the construction of the bioproduction infrastructure through strategic and active investment.

3.1.3. Germany

The German bioeconomy originates from the development of the industrial biotechnology in Germany, in which most research activities are dominated by the private sector, highly application-oriented, closely integrated with technology and the economy, and gradually extended to agriculture, forestry, and fisheries, which represent the basic role of the German bioeconomy.

The goal of the German bioeconomy is to combine the economy with ecology to ensure more sustainable utilization of biological resources. Its connotation is an economic form based on knowledge and technological innovation. The input end of the bioeconomy is to adopt bioengineering and biotechnology to ensure the least energy and resources consumption, and the output end is to provide sustainable products and abundant and extensive healthy foods from plants and animals with the least unwanted by-products and emissions adversely affecting ecosystems and biodiversity and to return the produced products to natural circulation as much as possible [54]. In terms of technology, new quantitative techniques, such as high-throughput analysis, automated imaging, and the capture and processing of large amounts of data for modeling are continuously improving the understanding of biological processes and contributing to the better achievement of the economic, social, and environmental goals of the German bioeconomy. At present, the concept of the bioeconomy in Germany covers agriculture and all manufacturing sectors, as well as the service fields of developing, producing, processing, or utilizing various forms of biological resources [55]. It involves many industries and sub-fields, including animal and plant breeding, food and beverage processing, wood, paper making, leather, textiles, the chemical and pharmaceutical industries, and energy. The development of the bioeconomy has also provided growth impetus for traditional industries such as mechanical and equipment engineering, construction, automobiles, and environmental protection. According to the analysis of National Research Strategy Bioeconomy 2030, a national strategic research report of Germany, Germany’s diversified and high-level biotechnology research system, domestic demand for high-quality food, and the trend of ecological transformation and industrial transformation are the main driving forces and favorable conditions for
the development of the German bioeconomy. However, the German bioeconomy also has weaknesses, such as research which is too scattered and lack of incentives, and at the same time, it faces development obstacles, such as slow technology transfer and insufficient interdisciplinary research.

In 2020, in the National Bioeconomy Strategy, Germany put forward two main lines of bioeconomy. One is to promote bio-knowledge and advanced technology to become the pillars of a future-oriented, sustainable, and climate-neutral economy, and the other is to focus on biomaterials produced in the industry. On this basis, six development goals are proposed: to develop bioeconomy solutions for the national “sustainable development agenda”; to recognize and utilize the full potential of the bioeconomy within ecological boundaries; to strengthen and apply biological knowledge; to establish a sustainable industrial feedstock base; to promote Germany as a leader in bioeconomy innovation; and to strengthen public participation and international cooperation.

3.1.4. Korea

The development of South Korea’s bioeconomy is driven by biotechnology like that of Germany, but the difference lies in the fact that South Korea’s biotechnology R & D is mainly organized and implemented by the government. Its biotechnology promotion policy began in 1982, when the Ministry of Science and Technology took biotechnology as the core strategic technology and then formulated the Genetic Engineering Promotion Law (now the Biotechnology Promotion Law) to provide a legal basis for promoting the development of biotechnology [56].

In terms of technology, post-genomic technologies, such as functional genomics and proteomics, have become an important part of Korea’s biotechnology competitiveness. In particular, the integration of biotechnology with nanotechnology and information technology is accelerating technological innovation. In addition, new fields, such as preventive medicine, personalized medicine, and reproductive medicine, are emerging, and the demand for research based on neuroscience is also increasing. At present, Korea’s bioeconomy mainly focuses on the medical care industry. With a large amount of investment led by the government, South Korea’s biomedical health care industry has made a series of achievements [57], such as stem cell therapy and biosimilars, as well as medical devices, such as molecular diagnostics and mobile devices, and has developed a number of top company groups with global competitiveness.

The future bioeconomy of Korea will further respond to the demand for sustainable development in the environment and energy and strengthen biosecurity against bioterrorism. On the economic front, various industries will continue to grow due to technology convergence and the industrialization of biotechnology, and the focus of biotechnology is expected to expand from the medical care industry to agriculture, the environment, oceans, energy, and the electronics industries. The development goal of South Korea’s government is to create a life-oriented society and a bioeconomy within 10 years and take measures in terms of papers, patents, human resources, and markets to enhance Korea’s international position in biotechnology. In September 2017, the Korean government formulated the Bio-economic Innovation Strategy in 2025: The Third National Framework Plan for Biotechnology Promotion, which plans to increase Korea’s share in the global biotechnology market from 1.7% in 2015 to 5.0% in 2025 [46]. The strategy puts forward five macro goals, including enjoying the best medical service in the world, enjoying a healthy life, opening a prosperous future with safe food technology, building a clean society with environmental protection technology, becoming a global leader in solving global problems, and building a bioeconomic and bioecological system at the global level; it puts forward four sub-goals closely related to people’s livelihoods, including developing 100 kinds of materials for new global drugs, creating 120,000 new jobs based on technology, increasing global technology export by 500%, and solving social problems through biotechnology research and development.
3.2. Two Drivers of Bioeconomic Development

The path from biotechnology to bioeconomy is the result of cooperation between the thrust of scientific and technological innovation and the pull of economic and social needs. The development pattern of the bioeconomy is also determined by the breakthroughs and applications of life sciences and biotechnology, as well as the policy objectives of different countries and regions around the world in relation to bioproducts, the circular economy, and sustainable development.

3.2.1. Innovation Promotion of Life Science and Biotechnology

Marx pointed out “The difference between various economic times is not what to produce, but how to produce it and what kind of labor materials to produce it with” [58]. The fundamental factor in the formation of an economic form is the production technology in the productive forces. Among them, the rise and fall of industry and the change and adjustment of the economic structure are all driven by the scientific and technological revolution and not transferred by human will. The basic elements of the bioeconomy are life science knowledge and biotechnology, and the development of the bioeconomy is an innovative process in the field of life science and biotechnology. Bioeconomic activity is a process of obtaining food, energy, pharmaceuticals, and other biological products sustainably through life science methods and modern biotechnology. Its essence is the application of biotechnology in agriculture, energy, medicine, and other scenarios, and it drives the process of the enterprise system and market operation mechanism reform.

In the past twenty years, among the “Top Ten Scientific Advances” selected by *Science* magazine, the achievements in the field of life science and biotechnology have always accounted for more than 50%, and the rapid development of knowledge and technology has supported the prosperity of the bioeconomy. At present, biotechnology is mainly used in three fields: agriculture, health, and industry. In agriculture, the main use of biotechnology at present is for animal and plant breeding and diagnosis. Transgenic technology and gene editing technology greatly improve crop breeding efficiency and can accurately obtain new crop varieties with high yield, high quality, high resistance, and green characteristics; genome selection and new reproductive technologies provide new opportunities for animal genetic improvement and genetic diversity protection [59–62]. High-throughput sequencing, automatic imaging, the ability to capture and process a large amount of data for modeling, etc., continuously improve the understanding of biological processes [63,64]. In terms of health, the application of biotechnology includes pharmacogenetics for the treatment, diagnosis, and improvement of prescription practice, functional foods and nutritional health products, and some medical equipment. Large-scale and interdisciplinary research fields of biological science and biotechnology, such as biology, synthetic biology, and nano-biotechnology, have driven the flourishing of emerging industries such as smart medicine and precision medicine [65]. In industry, the applications of biotechnology include the production of chemicals, plastics, and enzymes using biotechnology processes, environmental applications, such as the bioremediation of contaminated soil, biosensors, methods to reduce environmental impact or resource extraction costs, and the production of biofuels. The continuous improvement of biomanufacturing technology continues to improve the production efficiency of bioenergy and bio-based materials, and at the same time, it reduces energy consumption and pollution emissions in industrial sectors such as feed, textile, and paper through the use of microorganisms and enzyme preparations [66–68].

3.2.2. The Demand Pulls of Economic and Social Development of Each Country and Region

With the increasing pressure on the global population, energy, and environment, it is increasingly urgent to find an economic form that follows the laws of nature and realizes the harmonious development between man and nature. The attention of countries to the bioeconomy has changed from the pursuit and drive of economic interests to the planning and overall deployment at the policy level. In 2002, the United States began...
to implement the “Bio-Preferred Program”, which successively included 13,000 kinds of biological products in the mandatory federal procurement plan, which greatly promoted the supply and consumption of biological products [69]. In April 2018, the Organization for Economic Co-operation and Development (OECD) released Policy Challenges for a Sustainable Bioeconomy, pointing out that countries around the world have paid attention to the bioeconomy from the initial interest level to the mainstream policy [70].

The COVID-19 epidemic made people begin to re-examine the relationship between man and nature, the environment, and animals and plants and to pay more and more attention to reshaping lifestyles and optimizing the production and consumption of various products and to more sustainable development and utilization of biological resources. In particular, with the environmental externalities being recognized and internalized gradually, new concepts and development goals, such as the circular economy, renewability, resource utilization efficiency, and resilience have gradually become the new direction and focus of the bioeconomy and have been incorporated into the policy design frameworks of various countries. The Millennium Development Goals and The United Nations Sustainable Development Goals provide policy frameworks for many countries. Germany further defines the bioeconomy as a sustainable and climate-neutral economic system based on biological resources and biological knowledge [71]. “Sustainability” has become the starting point and destination of bioeconomic practice in many countries [72].

3.3. Characteristics of Bioeconomy

Technological innovation is comprehensive. Innovation is the change of a certain production factor, which is recombined with production conditions to form a new production function, thereby promoting economic development [73]. Industrial, scientific, and technological innovation is centralized, and decentralized manual production becomes centralized machine production, which promotes productivity. The scientific and technological innovation of the information economy is decentralized, and the efficient and refined division of labor makes it possible for a single organization and individual to carry out open innovation. The bioeconomy is based on comprehensive scientific and technological innovation, which comprehensively and profoundly changes the production and lifestyle of human beings until it changes the law of species evolution and everything from the inside out. The production, consumption, and distribution of products in the biological economy cover agriculture, food, industry, medicine, and other industries, which have changed the external environment of human beings and human beings themselves. The comprehensiveness of innovation is also reflected in the cross-integration of disciplines. Life science needs to cross-integrate with other disciplines, such as information and artificial intelligence, to produce new breakthroughs.

Industrial development is clustered. The new-age bioindustry includes biopharmaceuticals, biochemicals, bioenergy, and genetically modified crop industries [74,75]. The industry has the characteristics of high investment, high risk, high profit, and a long cycle; so, the innovation of life science and biotechnology shows the obvious development of aggregation, which is manifested in the aggregation of time and space. Time gathering means that once biotechnology makes an important breakthrough in a certain direction, it will produce a driving effect and drive a group of innovative achievements in a short period of time. Spatial agglomeration is mainly reflected in the development of the bioindustry in many countries around the world in areas where capital, science and technology, and talents are densely distributed. A number of bio-industrial parks have emerged as the times require, thus forming a perfect industrial chain and industrial clusters, and the industries are developing rapidly in clusters [76–79].

Development goals are global. The bioeconomy is based on renewable biomass resources, and its social and environmental benefits are remarkable [80,81]. In recent years, the urgent external demand for global issues, such as food and nutrition security, medical health, resources, and the environment for green transformation, has gradually internalized into the goal of bioeconomic development. By integrating new concepts and
goals, such as sustainability, the circular economy, renewability, resource efficiency, and resilience, the bioeconomy has continuously expanded the dimensions of development and continuously enhanced the systematicity and consistency of economic forms. In 2018, the EU strengthened and upgraded its bioeconomic strategy, and one of its important goals was to “maximize its positive role in promoting the 2030 Agenda, the Sustainable Development Goals (SDG), and the Paris Agreement” [37]. Many countries are gradually combining the bioeconomy with environmental protection, agricultural and rural development, etc. On the one hand, they reduce their dependence on fossil energy through the development and utilization of bio-based materials and bioenergy; on the other hand, they use modern agricultural biotechnology to improve and create new varieties of plants and animals with high yield, high quality, and green characteristics to reduce their dependence on natural resources, such as land and climate, and to improve the sustainability of related industries.

The regulatory requirements are high. Unlike other technologies, many biotechnologies involve human genes and other “human” factors in their development, production, and consumption. In most cases, biotechnological products are directly contacted or eaten by human beings. Animal experiments and human experiments have to be carried out in the process of technological innovation. In order to fully release and realize the potential of biotechnology and bioeconomy, the biosafety problem in the whole process from the laboratory to the market needs the government to implement safety management [82,83]. On the other hand, public opinion is also a key and decisive force in the wave of biotechnology innovation. Personal and social values will play an important role in the decision making regarding which technologies to explore and utilize. Social disputes about security, privacy, and ethics comprehensively reflect many complicated factors, such as the economy, politics, society, and even religion and culture in different countries and regions, which need policy guidance.

4. Perspectives: Accelerate the Breakthrough of Biotechnology and Improve the Supply Quality of Bioeconomic Factors

The development of the bioeconomy has promoted the strategic substitution of fossil energy. At the same time, it has a fundamental role and a far-reaching influence on emissions reduction, carbon neutrality, ensuring food security and food safety, improving the level of health, and eventually promoting the sustainable development of the global economy and society. Facing the historic opportunity brought by a new round of scientific and technological revolution and industrial transformation, biotechnology has gradually become the key generic technology together with information technology. Particularly in the post-COVID-19 pandemic era, the competition around biotechnology and bioeconomy will become more intense among countries; thus, updated strategies and higher goals of seizing the leading position of the bioeconomy have been put forward recently. “Bioeconomy” is not only enriching its form as an economic activity but also evolving as an interdisciplinary concept. It is high time to accelerate the spillover and transfer of biotechnology, closely combine the industrial chain of “biotechnology-bioindustry-bioeconomy” with the innovation chain, and realize the organic connection and simultaneous development from practice to theory (Figure 2).

4.1. Narrow the Gap between the Technology Innovation and Industrial Need

A comprehensive analysis of the latest bioeconomy strategies of various countries shows that countries tend to focus more on applying biotechnology to solve hot issues of public concern and to improve the competitiveness of their own industries, rather than the biotechnology innovation itself in the original strategies issued in the earlier stage. In terms of focusing on hot social issues, the European Commission proposed to raise EUR 52.7 billion to address societal challenges during the 2021–2027 period, of which about 60% is directly related to the bioeconomy [84]. The plan focuses the funding of research and innovation tasks on major disease prevention and control, innovative drug research and development, low-carbon technology promotion, and other issues affecting daily life.
In terms of improving industrial competitiveness, Britain will invest GBP 11 million to support the development of industrial biotechnology and GBP 4.5 million to support the industrial application of biotechnology [85]. Using biotechnology to solve hot social issues and improve industrial competitiveness conforms to the expectations of the people and the inevitability of social development and also maximizes the economic and social benefits of government investment.

4.2. **Fulfill the Role of Biotechnology in Low-Carbon, Green, and Sustainable Development**

In recent years, with the increase in population, the expansion of economic scale, the evolution of the production and consumption mode, and especially the over-exploitation and consumption of fossil resources, the bioeconomy has become an important green growth strategy in the world and has gradually become a powerful starting point to achieve the goal of sustainable development. The bioeconomy of developed economies such as the European Union and the United States has changed from technology-driven and economic benefit-stimulating to global sustainable development goal-oriented. The innovation direction of biotechnology should emphasize low-carbon, green, and recycling goals, in addition to meeting people’s needs for medical care, food, beauty, and security.

The bioeconomy and the “low-carbon economy”, “eco-economy”, and “circular economy” are all economic models under the concept of advocating harmonious development with the environment. Although they have slightly different emphasis on low emission, low exploitation, and high utilization, they overlap in the ways of realization and initiatives, and the demand direction for biotechnology is relatively consistent. Among them, the main goal of a low-carbon economy is to reduce greenhouse gas emissions by reducing fossil energy consumption and developing cleaner production technologies; the circular economy is characterized by low consumption, low emission, and high efficiency, and the economic growth model that conforms to the concept of sustainable development is a
fundamental change from the traditional economic growth model of the mass production of commodities, the consumption of resources, and excessive waste. Although there are some conceptual differences between the low-carbon economy, circular economy, and bioeconomy, they all need the support of biotechnology to link the common ideal of coordinating economic, environmental, and social goals. Therefore, in the process of formulating China’s future bioeconomic development strategy and policy, the three concepts can be integrated, and an integrated framework can be constructed to guide the biotechnology innovation in various fields, such as biological breeding, biomass energy, and biomanufacturing, to evolve towards low energy consumption, low emissions, and low pollution.

4.3. Maximize the Economic Attributes of Biotechnology

Biotechnology can effectively improve productivity and then bring economic benefits, but biotechnology research and development has positive externalities to a certain extent. Therefore, it is of great significance to stimulate the economic attributes of biotechnology, and it is necessary to ensure that the whole industrial chain of biotechnology R & D, production, and services can obtain reasonable economic returns, promote the deep integration of technology and the clinical field, technology and the market, and technology and industry, and promote the free and orderly flow of innovative resources among universities, research institutions, and enterprises. Through government procurement plus a reasonable market access pricing mechanism, all kinds of innovative entities are stimulated to actively provide biotechnology products and services. On this basis, we should speed up the definition of the difference between the bioeconomic circle, the bioeconomic industry, and the bioeconomic form and gradually move from the adjustment and transformation of the industrial structure at the meso level to the transition of the whole economy to a sustainable model.

4.4. Optimize the Policy Environment

In the field of life science and biotechnology, we should explore and improve the new national system under the condition of a socialist market economy, strengthen the strategic strength of national science and technology, and gather scientific and technological innovation resources to break through the key technologies that restrict the development of the bioeconomy. At the same time, there are still some uncertainties and challenges in the development of the bioeconomy, such as the potential negative impact of increasing the use of biomass on biodiversity and food production and the health and environmental risks associated with cutting-edge biotechnology. Based on adequate safety evaluation, we should promote the industrialization of biotechnology breeding in an orderly manner, deepen the reform of institutional mechanisms that restrict the development of the bioeconomy, such as clinical drug evaluation, marketing approval, clinical trial management, medical insurance, etc., and form a more inclusive and prudent adaptive supervision system, so that China’s transition to the bioeconomy will be more rapid, controllable and sustainable.

4.5. Promote the Theorization of Bioeconomy

Although the bioeconomy is growing vigorously worldwide, bioeconomics research is still at the initial stage, especially in the Chinese scientific community, which is mainly focusing on the research of the bioeconomy life cycle assessment, biomass transformation, and so on. There is still a lack of the construction of a theoretical framework compared to that of the agricultural economics and industrial economics. At the same time, there are still some uncertainties and challenges in the development of the bioeconomy, including the potential negative impact of the increasing use of biomass on biodiversity and food production, as well as the health and environmental risks associated with the new biotechnology. These problems in the process of bioeconomic development indicate that it needs to accelerate the research of bioeconomic theory and assessment models, based on which the supervision system of biotechnology and the market can formulate in time, ensuring that the transition to the bioeconomy is more rapid, controllable, and sustainable.
Author Contributions: Conceptualization, X.W. (Xun Wei) and X.W. (Xiangyuan Wan); methodology, J.L., A.P. and Q.L.; software, J.L., A.P. and Q.L.; validation, Y.L. (Yan Long) and Y.L. (Yan Leng); formal analysis, J.L. and X.W. (Xun Wei); resources, X.W. (Xiangyuan Wan); writing—original draft preparation, J.L., A.P., and Q.L.; writing—review and editing, X.W. (Xun Wei), L.Z., S.W. and X.W. (Xiangyuan Wan); supervision, X.W. (Xun Wei) and X.W. (Xiangyuan Wan); project administration, Z.D.; funding acquisition, X.W. (Xiangyuan Wan). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key Research and Development Program of China (2021YFF1000302, 2021YFD1200700) and the Fundamental Research Funds for the Central Universities of China (06500060).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data are shown in the main manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References
2. Calicioglu, O.; Bogdanski, A. Linking the bioeconomy to the 2030 sustainable development agenda: Can SDG indicators be used to monitor progress towards a sustainable bioeconomy? New Biotechnol. 2021, 61, 40–49. [CrossRef]
7. Patermann, C.; Aguilar, A. A bioeconomy for the next decade. EFB Bioecon. J. 2021, 1, 100005. [CrossRef]
16. Heiman, T. Bioeconomy and SDGs: Does the bioeconomy support the achievement of the SDGs? Earth’s Future 2019, 7, 43–57. [CrossRef]
49. Ronzon, T.; M’Barek, R. Socioeconomic Indicators to Monitor the EU’s Bioeconomy in Transition. *Sustainability* 2018, 10, 1745. [CrossRef]