South China University of Technology

BOAO FORUM FOR ASIA INNOVATION REPORT 2023

博鳌亚洲论坛创新报告 2023

Boao Forum for Asia
Innovation Report 2023

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Chapter Ⅰ
Trends in Global Scientific and Technological Innovation

Ⅰ. Trends in Scientific and Technological Innovation

ⅰ. A New Landscape in Regional and National Scientific and Technological Innovation

Expedited scientific and technological innovation is reshaping the global innovation landscape. According to a research report released by the World Intellectual Property Organization in 2023, Switzerland has led Europe for the 13th consecutive year. Meanwhile, it has been at the forefront of innovation output globally. Sweden has risen to second place, excelling in business sophistication, infrastructure, human capital, and research. Eight Nordic and Baltic economies are also experiencing collective growth. The United States stands out in multiple innovation indicators in North America, including global R&D investments, venture capital inflow, and top-notch universities. Singapore has entered the top five in Asia, emerging as a leader in Southeast Asia, East Asia, and Oceania. China, South Korea, Japan, and Israel are ranked among the global top 15, with China as the only middle-income economy in the top 30. The Middle East has seen significant progress in its innovation rankings. According to a holistic analysis of this new landscape of global innovation capabilities, North America, led by the United States and Canada, emerges as the world's most innovative region. Europe maintains its leading position among the top 25 economies, with 16 countries on the continent represented on the list. Southeast Asia, East Asia, and Oceania are working to close the gap with Europe, while Central and South Asia are gradually catching up with Latin America and the Caribbean. India leads in Central and South Asia, Israel leads in North Africa and West Asia, Saudi Arabia enters the top 50, and South Africa leads in knowledge and technology output in Sub-Saharan Africa. ① In terms of innovation performance, European Union countries are classified into four performance groups: Innovation leaders, strong innovators, medium innovators, and emerging

① United Nations World Intellectual Property Organization. *Executive Summary-Global Innovation Index 2023*, p. 11-26.

innovators. Innovation leaders are primarily concentrated in Northern and Western Europe, while mid-level and emerging innovators are clustered in Southern and Eastern Europe. ①

ii. Discipline Aggregation Expedites the Scientific and Technological Innovation

Cross-fertilization generates insights, and aggregation cultivates uniqueness. In the "big science" era, scientific and technological innovation's scope, depth, and complexity are increasing by orders of magnitude, gradually blurring the boundaries between science and technology and between different technologies. Against this backdrop, it is difficult to address complex problems and achieve significant breakthroughs using traditional research paradigms based on a single discipline. New paradigms like "convergence science", "open science", and "computational social science" now emphasize interdisciplinary fusion innovation. For example, robots have been widely applied in industry, agriculture, healthcare, and national defense, and the research and application of robotics require interdisciplinary fusion. This process aggregates key technologies, such as new materials, automatic control, data technology, 5G communications, and artificial intelligence. In developing specialized robots, for example, the fusion of multiple disciplines is essential; orthopedic surgery robots involve the fusion of disciplines like medicine, mechanics, biomechanics, and computer science. As such, joint participation and close collaboration among institutions, including universities, companies, and hospitals, are pivotal for product approval, transformation, and industrial application.

iii. Scientific and Technological Innovation Focuses on Digital Intelligence Technologies

Digital technology innovation drives the global digital intelligent transformation of industries. In 2023, global scientific and technological innovation and competition increasingly focused on digital intelligence technologies. Core technology areas of global digital intelligence technology innovation include the following:② Developing the metaverse technology: The metaverse is a shared virtual space that blends physical and digital realities augmented by virtual technology and can provide enhanced immersive experiences. Superapp technology: A superapp is an application that consolidates the features of various applications, platforms, and ecosystems. It not only possesses its own set of features but also serves as a platform for third parties to develop and release their micro-applications. Adaptive AI

① European Commission. *European Innovation Scoreboard 2023*, p. 1-2.

② Gartner. *Top 10 Strategic Technology Trends for 2023*, published in *Software and Integrated Circuit*, 2022 (11): 10-11.

technology: Adaptive AI systems, through continuous and repeated training of models and learning with new data in runtime and development environments, can swiftly adjust to real-world changes that cannot be foreseen or acquired during the initial development. Optimizing digital immune systems: Digital immune systems enhance system resilience and stability by integrating data-driven operational insights, automation, rigorous testing, software engineering in IT operations, and implementing security in supply chains. Applied observability technology: Applied observability feeds back observable feature data in a highly coordinated and integrated manner, thereby creating a decision loop to enhance the effectiveness of organizational decision-making. AI trust, risk, and security management: AI trust, risk, and security management require participants from different business departments to collaborate in implementing new measures. Industry cloud platform technology: Enterprises can utilize the packaging feature of an industry cloud platform as a basic module to create unique and differentiated digital business projects. This facet enables enterprises to avoid vendor lock-in while enhancing agility, promoting innovation, and reducing time to market. Wireless-value realization: With no dominant technology, enterprises are adopting various wireless solutions to meet their demands in different scenarios, including office Wi-Fi, mobile device services, low-power services, and radio connections. ①

iv. Scientific and Technological Achievements Applied in the Livelihood and Healthcare Industries

In 2023, scientific and technological innovation achievements found wide application in sectors concerning people's livelihood and healthcare. Efforts primarily concentrated on developing products aimed at promoting longevity, cell repair, regenerating body parts, discovering novel drugs, and creating anti-aging supplements. Moreover, there was a drive to foster the development of superapps. In particular, global giants in scientific and technological innovation are consistently broadening their horizons. Leveraging applications, they aim to transform into integrated platforms offering diverse functions, encompassing information, payment services, shopping, gaming, and food delivery, with the ultimate objective of enhancing consumer convenience across various domains. There was an accelerated advancement in financial technology regeneration, with companies progressively evolving in two pivotal directions: (1) Expanding into new business domains and innovating new product features and (2) endeavoring to launch products and business diversification strategies. Now gaining traction, virtual power plants have emerged through optimization in energy coordination and utilization. They play a critical role in reducing dependence on coal and natural gas, stabilizing power grids, and ultimately lowering household energy expenses.

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① D. J., S., *Global Top 11 Technology Innovation Trends for 2023*, published in *Chinese & Foreign Corporate Culture*, 2023 (9): 20-21.

Smart healthcare also saw expansion efforts involving the use of sensors to gather health-related data from patients to foster more proactive diagnoses and treatments. The reinforcement of regenerative agricultural technology took place, intending to restore soil health, preserve ecological balance, and conserve the environment. This approach involves planting trees between crops, minimizing soil disturbance, abstaining from synthetic fertilizers and pesticides, and adopting rotational grazing techniques.

v. Fierce Competition Leads to Dramatic Changes in the Science and Technology Ecosystem

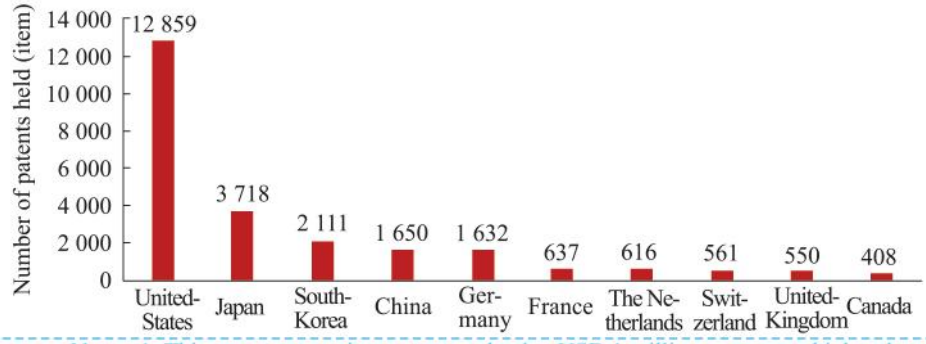
Recently, major developed countries worldwide have strategically planned and implemented policies and laws concentrating on cutting-edge technologies in the latest phase of the scientific, technological, and industrial revolutions. These technologies include big data, artificial intelligence, quantum technology, 5G/6G communications, new energy, and new materials. Furthermore, these countries have implemented various measures to stimulate domestic innovation while curbing innovations from foreign counterparts. These measures include significant hikes in R&D investment, subsidies for industrial applications, talent attraction, export restrictions, hindering collaborations and exchanges, and imposing sanctions on competitors. Their ultimate objectives are to sustain their current technological advantages over an extended period and efficiently secure new technological advantages in the competition for a dominant position in the upcoming phase of the scientific and technological revolution. Consequently, this intensity has resulted in an unparalleled level of competition among countries in the science and technology industries and has instigated significant shifts in the original R&D and industrial ecosystems of global cutting-edge technologies. As an illustrative point, since 2021, global high-end chip R&D and industrialization have been consolidated into three distinct R&D and industry ecosystems: The United States, the European Union, and East Asia. This division has disturbed the previously well-established ecosystem in which the R&D and industrial chains of chips were structured based on considerations like resource endowments, market demands, and R&D strengths. Consequently, critical problems arise, including redundant global R&D and investments and a deficiency in market demand. Moreover, similar rigorous competition and changes in the ecosystem have surfaced in other domains of cutting-edge technology, such as artificial intelligence, quantum technology, 5G/6G communications, and new energy.

Ⅱ. Trends in Patent Distribution

i. The Number of Applications for High-Value Patents Reaches Record Highs

In 2022, global PCT patent applications experienced a moderate 0.3% increase to

278,100, marking a record-breaking single-year quantity. India and South Korea saw significant rises in PCT applications, mirroring the global challenges faced in the political and economic spheres. Asia upheld its position as the leading contributor to international patent applications, accounting for 54.7% of the total. India and China made strides in global patent applications, with China experiencing a consecutive decline in growth rate from 6.8% in 2021 to 3.1% in 2022. Meanwhile, India experienced a surge of 31.6% in patent applications in 2022, maintaining growth for the 11th consecutive year and leading among the top 10 applicants. Furthermore, in 2022, the number of international applications filed through the Hague Agreement Concerning the International Registration of Industrial Designs of the World Intellectual Property Organization grew by 11.2%. China continued as the leading contributor to PCT applications, marking a 0.6% year-on-year increase. The top four contributors in terms of application numbers included the United States, Japan, South Korea, and Germany. The growth of PCT applications in Asia outpaced other regions, with the overall share growing from 54.2% in 2021 to 54.7% in 2022.① The United States led the top 10 countries in high-value patents with 12,859, 3.4 times more than Japan's 3,718 patents, securing the second position. South Korea secured the third place with 2,111 high-value patents, while China held 1,650 patents, ranking it the fourth place and accounting for only 12.8% of the United States' total. Germany followed closely with 1,632 patents. France, the Netherlands, Switzerland, the United Kingdom, and Canada filled the sixth to tenth positions. While China leads in digital technology patents, its count in high-value patents lags considerably behind the United States, Japan, and South Korea.②



Notes: 1. This report categorizes patents valued at USD 1 million or more as high-value patents.
2. The patent search spans from January 2012 to December 2021.
Data Source: AMiner

Fig. XXX Top 10 Countries Worldwide for High-Value Patents in Digital Technology

Data Source: *Research Report on Global Digital Technology Development for 2023*

① Best Lawyers. *Report on Global Trends in International Patent Applications for 2023*, https://mp.weixin.qq.com/s/JDkU5X-7o-Qnyf6wxwGQow.

② AliResearch. *Research Report on Global Digital Technology Development for 2023*, p. 21.

ii. The Number of PCT Patent Applications in Digital Technology Is at the Forefront

Regarding technology fields, computer technology leads in global PCT international patent applications at 10.4%, followed by digital communications at 9.4%, electrical machinery at 7.1%, medical technology at 7%, and measurement at 4.6%. Eight of the top 10 technology fields in 2022 experienced growth, with digital communications and computer technology leading at growth rates of 8.7% and 8.1%, respectively, followed by semiconductor technology at 6.8%, biotechnology at 6.7%, and electrical machinery at 6.1%. Following a significant surge in health-related technology fields in 2021, the digital technology field re-emerged as the fastest-growing field for PCT applications in 2022.① This trend mirrors the need for rapid expansion in the digital economy, highlighting the crucial roles of digital communications and computer technology in its development and their guidance in global scientific and technological innovation.

iii. Technology Enterprises Take the Lead in High-Value Patents

High-tech enterprises are the primary drivers of scientific and technological innovation, influencing a country or region's innovation capability based on the number and scale of high-tech enterprises within that area. Huawei, a Chinese company, retains its position as the leading PCT patent applicant, with 7,689 PCT applications disclosed in 2022. Samsung Electronics from South Korea secures the second place with 4,387 applications in 2022, followed by Qualcomm from the United States at 3,855, Mitsubishi Electric from Japan at 2,320, and Ericsson from Sweden at 2,158. Samsung Electronics surged by 44.3% among the top 10 applicants, securing the second spot. Nippon Telegraph and Telephone (NTT) from Japan witnessed significant growth, climbing five places to the seventh position in 2022, achieving a growth rate of 24.9%. Among the top 10 institutions holding high-value patents in digital technology globally, the United States accounted for five, China for two, and one each from South Korea, the Netherlands, and Japan. Samsung led its peers with 1,061 high-value patents, followed by Microsoft and Google from the United States in second and third places, respectively. Huawei and Alibaba from China claimed the fifth and ninth positions on the list, holding 373 and 261 patents, respectively. These holders of high-value patents not only reflect current trends in scientific and technological innovation but also highlight these enterprises' leadership in global digital technology innovation.②

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① Best Lawyers. *Report on Global Trends in International Patent Applications for 2023*, https://mp.weixin.qq.com/s/JDkU5X-7o-Qnyf6wxwGQow.

② AliResearch. *Research Report on Global Digital Technology Development for 2023*, p. 22.

iv. The Number of Patent Applications Continues to Grow in East Asia

In Asia, China, Japan, and South Korea continue to exhibit robust growth in patent applications and approvals. By September 2023, China had accumulated 4,805,000 valid invention patents and 45,122,000 trademarks, maintaining its global top position for PCT international patent applications for four consecutive years. Patent-intensive and copyright industries contribute 12.44% and 7.41%, respectively, to the GDP, significantly propelling the high-quality development of the economy.① According to industry reports, China possesses 387,989 digital technology patents, surpassing the United States by 2.9 times and exceeding the combined total of the last nine countries by 1.6 times. China's R&D capability in digital application technology is a global competitive force.② In 2022, Japan experienced growth in overall applications for invention patents, reaching a total of 289,530. The Japan Patent Office accepted 48,719 PCT international patent applications, reflecting a slight decline from the peak in 2019. Additionally, design applications, applications for utility models, and trademark registration applications reached 31,711, 4,513, and 170,275, respectively.③ In South Korea, the Korean Intellectual Property Office (KIPO) released the statistical analysis result in September 2023 of patent applications in technology fields during the Fourth Industrial Revolution from 2013 to 2022. The result showed that over the past decade, technology patent applications increased by an average of 14.7% per year. Notably, applications for artificial intelligence technology patents led to growth in technology fields during the Fourth Industrial Revolution, with an annual average growth rate of 37.8% for convergent technologies.④ This suggests that East Asia has emerged as the most dynamic region for scientific and technological innovation and the foremost region globally in terms of patent distribution.

v. The Guangdong-Hong Kong-Macao Greater Bay Area Outperforms Other Bay Areas

Benchmarking itself against other global bay areas like New York and Tokyo, the

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① *Booming Trend in Patent Innovation in Digital Economy*, published in the *CPPCC Daily*, November 10, 2023, Issue 6.

② AliResearch. *Research Report on Global Digital Technology Development for 2023*, p. 6.

③ Intellectual Property Rights Information, Chinese Academy of Sciences. The *Japan Patent Office Issues the* 2022 *Administrative Report on Patents*, http://www.zhimomo.com/mobile/e/action/ShowInfo.php?classid=17&id=664.

④ M. Y., W., *South Korea Issues the Report on Intellectual Property Trends for 2022*, https://www.worldip.cn/index.php?m=content&c=index&a=show&catid=64&id=2377.

Guangdong-Hong Kong-Macao Greater Bay Area focuses on four key patent indicators: Invention patents, PCT patents, family patents, and patent citation frequency. It has surpassed its global counterparts in comprehensive patent capabilities. In terms of the number of invention patents, the Guangdong-Hong Kong-Macao Greater Bay Area maintains a positive trend in innovation, ranking first among the four major bay areas in the annual average growth of released invention patents. From 2017 to 2021, the total number of invention patents released in the Guangdong-Hong Kong-Macao Greater Bay Area reached 1,769,000, with a compound growth rate of 21.74%, ranking first among the four major bay areas. In 2021, the number of invention patents released increased by 21.74%, reaching 449,600, surpassing the combined total of the other three bay areas. In PCT patents, the Guangdong-Hong Kong-Macao Greater Bay Area ranks second only to the Tokyo Bay Area in the number of patents released. Between 2017 and 2021, PCT patents released in the Greater Bay Area totaled 136,800, surpassing the figures for the New York and San Francisco bay areas by 3.19 times and 3.81 times, respectively. Over the past five years, the compound growth rate of PCT patents released in the Guangdong-Hong Kong-Macao Greater Bay Area reached 9.82%, indicating promising development prospects. In family patents, both the number and compound growth rate in the Guangdong-Hong Kong-Macao Greater Bay Area lead among the four major bay areas. From 2017 to 2021, the total number of family patents released in the Guangdong-Hong Kong-Macao Greater Bay Area reached 3,032,100, more than double the combined total of the other three major bay areas, with a compound growth rate of 20.24%. This showcases the Greater Bay Area's leading position in patent market coverage. In the new-generation information technology realm in the① Guangdong-Hong Kong-Macao Greater Bay Area, the share of invention patents reaches 62.37%, with the digital creative industry accounting for 19.63%. Concurrently, industries such as new energy vehicles, related services, new materials, and the biotechnology industry have also significantly contributed, injecting diverse impetus into regional innovation.

Ⅲ. Trends in the Technology Industry

ⅰ. Arrangements Are Expedited for the Industrialization of Cutting-edge Scientific and Technological Innovation Achievements

The year 2023 marks a pivotal stage in accelerating the industrial application and

① Guangzhou Daily Data & Digit Institute. *Report on Collaborative Innovation Development in the Guangdong-Hong Kong-Macao Greater Bay Area (2022)*.

arrangements for innovation achievements in cutting-edge technologies during the Fourth Scientific and Technological Revolution. Big data and cloud computing are driving industrial transformation. In the digital age, the industrial application of data analytics technology is a significant driver of enterprise modernization. Cloud computing, as a proven approach to big data analysis and storage, has enhanced the efficiency and convenience of business operations. The potential of artificial intelligence for industrial applications is continuously being explored. As a strategic core technology, AI is poised to become a pivotal driving force in industrial transformation, with applications across various sectors, including medical services, intelligent manufacturing, agriculture, and transportation. Concurrently, the industrial application of quantum computing technology is at a crucial phase. Next-generation quantum computers are anticipated to surpass classical computers, opening up new applications in scientific computing, simulation, and machine learning. Quantum computers will also be promoted more widely in areas such as intelligent transportation, intelligent manufacturing, and intelligent finance. The scale of the industrial application of robots and automation is expanding into diverse sectors, including medical services, equipment manufacturing, education, and national defense. Biotechnology is spearheading a revolution in life sciences, with proven applications of biotechnologies such as gene editing and clustered regularly interspaced short palindromic repeats (CRISPR) in pure scientific research. These technologies also show promising prospects in fields such as medicine, agriculture, and environmental protection. Significant progress has been achieved in the development of digital twin technology. This technology offers various advantages, including reducing the R&D costs of products and machinery, streamlining production processes, and enhancing efficiency and quality. The application scenarios of digital twin technology will extend across more industries, contributing to broader applications in reshaping the mode of production and product design. Smart homes enter the intelligent era, with smart home devices seamlessly integrated into people's daily lives. This integration provides a more convenient and efficient living experience.

ii. Investments in Major Economies Are Increasing

Despite a myriad of challenges in global scientific and technological cooperation, exchanges, and investment, the R&D expenditures of major economies around the world have been on the rise since 2022. This is driven by their competition for dominance in scientific and technological innovation and their need to boost economic growth. In 2022, the United States allocated USD 713.2 billion for Research and Development (R&D), a figure almost double that of the European Union's investment. This represented 2.55% of the US GDP. During the same period, China invested USD 459 billion (equivalent to more

than RMB 3 trillion) in R&D, accounting for 2.55% of its GDP. This marked the seventh consecutive year of growth, with China's investment being 64.18% of the United States and surpassing Japan's R&D expenditures in Asia by more than threefold. The European Union committed USD 378 billion to technology R&D, constituting 2.27% of its GDP and showing a growth of 8.9% from the previous year. Japan directed USD 135.4 billion towards research funding in 2022, amounting to 2% of its GDP. In the same timeframe, South Korea's R&D investment totaled RMB 611.18 billion, representing 4.81% of its GDP. According to the 2022 *EU Industrial R&D Investment Scoreboard*, the growth rates of R&D for American and Chinese companies were 16.5% and 24.9%, respectively, maintaining their lead over European Union companies. Meanwhile, the United States continued to dominate with 822 top-notch R&D investment companies, followed by China with 679 companies, the European Union with 361 companies, and Japan with 233 companies. ①

iii. Asia Leads in Industrial Clusters for Scientific and Technological Innovation

Among the global top 100 science and technology industry clusters, Tokyo-Yokohama in Japan and four other major clusters in Asia take the lead. The top five science and technology clusters are all based in East Asia: Tokyo-Yokohama (Japan), Shenzhen-Hong Kong-Guangzhou (China), Seoul (South Korea), Beijing (China), and Shanghai-Suzhou (China). ② China has secured the position as the economy with the most science and technology clusters, boasting 24 clusters ranked among the top 100. This marks a slight increase from 21 the previous year, with a median growth rate of 12.1%. Hefei and Qingdao stand out as the two clusters with the fastest growth globally, at 21.6% and 19.4%, respectively. China is followed by the United States with 21 science and technology clusters, Germany with nine, and Japan, Canada, India, and South Korea each with four science and technology clusters. In addition to China, other middle-income economies have recorded robust growth in science and technology output in their clusters, particularly India, which boasts four top-tier science and technology clusters. ③ The surge in the number of

① The Institute for Fintech Research, Tsinghua University. *Report on Global Financial Technology Investment and Financing Trends (H1 2023)*. Website: https://thuifr.pbcsf.tsinghua.edu.cn/info/1011/2518.htm.

② Zhu, T., The *Wave of Innovation Brings Hope to Global Development*, published in the *Social Sciences Weekly*, October 19, 2023, Issue 1.

③ United Nations World Intellectual Property Organization. *Global Innovation Index 2023-Science and Technology Clusters Ranking 2023*, p. 1-2.

science and technology industry clusters in Asia signifies a sustained improvement in Asia's innovation capability and industrialization level. Meanwhile, an analysis of the science and technology intensity of the top 100 clusters indicates that the most science- and technology-intensive clusters are primarily found to be in Europe and the United States, particularly Cambridge (UK), San Jose-San Francisco (California, US), Oxford (UK), Eindhoven (the Netherlands), and Cambridge (Boston, US). Daejeon in South Korea emerges as an Asian cluster with the highest science and technology intensity. Only Beijing is included on the list from China. ①

① United Nations World Intellectual Property Organization. *Global Innovation Index 2023-Science and Technology Clusters Ranking 2023*, p. 73-74.

Chapter Ⅱ
Challenges Facing Global Scientific and Technological Innovation

Ⅰ. Challenges for R&D Investment

Due to interference and restrictions caused by non-market factors such as trade protectionism, export restrictions on technology as well as scientific and technological products, and the reconstruction of science and technology-related industrial chains, there have been significant changes in the quantity and flow direction of expenditures on scientific research and experimental development across the globe. Consequently, the landscape for global scientific and technological innovation as well as the science and technology-related industrial structure are both constantly being influenced by these factors.

i. Enterprises Suffer Decreased R&D Input and Unbalanced Direction of Flows

A large part of foreign direct investment (FDI) funds often flows to science and technology projects. However, in 2022 global FDI dropped by 12% to USD 1.3 trillion, and the amount of FDI in all major countries fell significantly. In 2022, the US recorded USD 285 billion in FDI, more than any other country in the world, but this figure was over USD 100 billion less than the previous year, representing a decrease of as much as 26.5%. Meanwhile, in 2022 China attracted USD 189 billion in FDI, a slight increase over 2021. Global FDI flows are mainly concentrated in developed economies as well as emerging and developing economies. In particular, in the world's 46 least developed countries the total amount of foreign investment attracted was just USD 22 billion. According to the data released by PitchBook, in the first quarter of 2023, a total of EUR 11.8 billion flowed to European startups, which was approximately 57% lower than in the first quarter of 2022. Meanwhile, the specific number of transactions decreased by nearly one-fifth from the previous quarter. The scale of scientific and technological investment and risky financing also decreased sharply at the beginning of 2023. The amount of financing for startups in the US during the same period was approximately USD 37 billion, the lowest quarterly level in 13 quarters. At the same time, in 2023 a number of "star" unicorn enterprises in North America, including those in the sharing economy industry, the automobile industry and the biotechnology industry, went bankrupt one after the other.

ⅱ. Government Funds Largely Flow to Fields Involving Cutting-edge Technology

Since 2022, developed countries like the US, the UK, Japan, South Korea and countries in the EU have increased government support for R&D input and industrialization in high-tech fields such as chips, AI, quantum computing, new energy and 5G communication by adjusting scientific and technological innovation strategies and formulating laws and regulations on scientific and technological investments. The US planned to invest USD 280 billion in chips and other high-tech fields, while the EU has invested EUR 43 billion in the R&D and manufacturing of chips. Other developed economies are also increasing government investment in R&D, with the hope that this government investment in R&D will drive market entities to jointly increase R&D funds. However, this process has been accompanied by the promulgation of a series of laws and policies that deliberately cut off science and technology-related industrial chains, restrict the export of technology and of scientific and technological products and violate market rules.

ⅲ. Some R&D Investment Has Been Removed from China and Europe

With the global economic downturn, the previous stable pattern of industries and their R&D investment has been broken, and some investment in technology R&D has been gradually removed from China and Europe or is not allowed to flow to China. Investments in medical innovation as well as R&D and medical products are typical examples. In 2020, the financing scale of European companies was more than double what it was in 2019, but then it declined in the subsequent two years. In 2018 and 2019, European companies received a total investment of USD 15.2 billion on average, but only USD 7.8 billion in 2022. They received an average investment of over USD 26 billion in the three years from 2020 to 2022. In 2020 and 2021, the trading shares and absolute values of Chinese companies both jumped, but then in 2022, they decreased by 59%, finishing 11% lower than 2019 levels. This trend has further intensified since 2023.

Ⅱ. Challenges Facing Scientific and Technological Cooperation

ⅰ. Science and Technology Supply Chains Show a Long-term Trend Toward Localization

Global collaboration in the science and technology industry is facing challenges. From the standpoint of prioritizing national interests, placing domestic concerns at the forefront, and mastering the leading power of scientific and technological innovation, it has become the new normal for major developed countries to close off their domestic markets or only open them with conditions. Meanwhile, various countries are accelerating the reconfiguration of their

industrial chain layouts, attempting to regain control of the "discourse power" in terms of the national economy and people's livelihoods, especially when it comes to public health and safety. Countries are even trying to forcibly change international supply chain patterns that were formed by globalization. The regionalization of innovation has therefore emerged as a new trend. The localization, domestication and self-controllability of supply chains and core technologies in the science and technology industry have become a trend. For example, the implementation of the *CHIPS and Science Act of 2022* in the US marks the official entry into force of an act authorizing high levels of subsidies for a single industry. This act authorizes considerable subsidies and tax breaks for the US domestic chip industry and requires any company receiving US subsidies to manufacture chips within the US. The US intends to use this act to make up for shortcomings in the manufacturing process of the semiconductor industrial chain and incentivize Taiwan Semiconductor Manufacturing Company, Samsung and other global giants in wafer manufacturing to build factories in the US. As a result, the global industrial chain for chips has been localized by one country. In the future, the AI industry, the new energy industry, the quantum technology industry, the 5G industry and various other industries might be forcibly cut off from global industrial chains and be localized partially or completely by one country.

ii. Collaboration and Exchanges Related to Scientific and Technological R&D Continue to Encounter Obstacles

As the world's two largest economies, the US and China have the largest scale of scientific and technological innovation, the greatest number of achievements in scientific and technological innovation, and the highest level of scientific and technological industrialization worldwide. Over the years, the US, China and other countries have been conducting close scientific and technological collaborations and exchanges for mutual promotion and achievements, guaranteeing the enhancement of capabilities in global scientific and technological innovation. However, since 2018 developed countries have issued a series of executive orders, policies and laws that interfere with and impede collaboration in scientific and technological R&D projects, scientific and technological information exchanges, scientific and technological services, the flow of scientific and technological talent, opportunities to study abroad for science majors and more. For example, between 2015 and 2020 the number of papers co-authored by scientists from China and the US jumped from 3,412 to 5,213 per year, more than any other pairs of two countries in the index compiled by *Nature*, but this number then began to decline rapidly starting in 2021. Under the *U.S.-China Science and Technology Cooperation Agreement*, a landmark cooperation agreement that was signed between China and the US in 1979, both sides have achieved fruitful results through cooperation in many fields such as aviation and aerospace, information technology and energy technology. This agreement is renewed every five years, but as for whether or

not it can be renewed again after its expiration in 2023, this has become problematic. Such interference and obstacles will have a severe impact on scientific and technological innovation across the globe.

ⅲ. There Is No Reasonable Basis for Isolating Scientific and Technological Cooperation and Exchanges

Since 2018, some developed countries have been constantly increasing the use of policy tools for science and technology sanctions, engaging in discussions with other governments to establish an updated version of a coordinating committee for export controls, and aiming to formulate effective rules with other countries with advanced technology in order to prevent the leakage and export of sensitive key technologies to relevant countries. The true aim of such behavior is to attempt to monopolize cutting-edge science and technology and to seek global hegemony in science and technology. At the same time, these countries impose unilateral sanctions on the technology enterprises and university research institutes of other countries on "unwarranted" grounds such as national security, violation of their domestic laws, and violation of their values. This trend will continue to intensify in 2023. This manual blocking of global innovation and R&D chains as well as science and technology-related industrial chains does not conform to WTO rules and deviates from the market rules governing scientific and technological innovation. For example, some countries have strengthened diplomatic ties with the EU based on shared "democratic values" as well as the standardization of cross-border data flow and transmission, which will change the current fragmented and decentralized state of data governance and intensify the global competition over digital regulations.① Certain countries have also launched measures like the *Declaration for the Future of the Internet* along with the UK, Australia, Japan, countries in the EU and other countries, formulating future Internet rules designed to constrain China.② However, there are neither just causes nor sufficient grounds for doing so.

Ⅲ. Challenges Facing Scientific and Technological Regulation

ⅰ. Emerging Science and Technology Incur Ethical and Legal Risks

Cutting-edge science and technology related to the latest scientific and technological revolution is generating significant ethical and legal risks. Without effective regulation, these

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① Refer to Hou X., Yang J. & Zheng S.: *Development Trends in Global Cutting-edge Technology Competition in the First Half of 2022*. *National Defense Science & Technology Industry*, 2022 (11): 59-61.

② Refer to Liu, D.: *Tech Giants are Reshaping Geopolitical Patterns: Examining the Digital Power Competition in the Russia-Ukraine Conflict*. *Dongfang Journal*, 2022 (02): 30-38.

could seriously affect the in-depth R&D and industrial application of science and technology. For example, gene editing technology impacts and poses a challenge to reproductive ethics, family ethics, inheritance law, marriage law and adoption law. Meanwhile, facial verification technology faces ethical and legal risks such as the disclosure of biological privacy data and more convenient deception. Since 2022, generative AI has ushered in rapid growth in R&D and applications, but it has also incurred a series of risks. The first of these risks lies in authenticity. It is impossible to guarantee the authenticity and accuracy of content generated by AI. The improper application of false information will also lead to further problems in terms of injury and liability attribution, and it is difficult for the law to distinguish between different risk assumptions. The second risk lies in prejudice and discrimination. Generative AI uses training data from human society, and so it might inherit these same discriminatory factors that are present in human society. The third risk lies in subject dependence. The dependence risks mentioned here include functional dependence on generative AI as well as emotional dependence on generative AI. Users clearly know that ChatGPT interactive dialogue robots are not real humans, but they might still treat them as if they were human beings, become dependent on them, and even avoid interpersonal communication in the real world, thus affecting the cultivation of individual social emotions and communication capacities.

ii. Ethical and Legal Regulation Is Not Keeping Up with the Progress of Scientific and Technological Innovation

When it comes to regulating frontier technology, in various countries the common practice is that ethics comes first and the law follows. When a technology is in the early stages of R&D and application, the possible risks, consequences and responsibilities remain unknown, and so the self-discipline and ethical norms of the industry can be formulated for regulation. When a technology is in the mature stages of R&D and application, the possible risks, consequences and responsibilities are basically clear and stable, making it easier for laws to be formulated for regulation. At present, a new round of scientific and technological revolution is in full swing, but ethical and legal regulation lags far behind. This will objectively affect the progress of scientific and technological innovation and industrialization. For example, the R&D and industrial application of generative AI technology is accelerating, but ethical and legal regulation is lagging noticeably behind. In October 2022, the US published the *Blueprint for an AI Bill of Rights: Making Automated Systems Work for the American People*, followed by the *National Artificial Intelligence R&D Strategic Plan* in May 2023. However, formal legislation will take some time. In September 2021, China issued the *Ethical Norms for New Generation Artificial Intelligence*, and then in July 2023 it released an administrative regulation titled *Interim Measures for the Administration of Generative Artificial Intelligence Services*. In 2021, the EU announced the first draft of the *Artificial Intelligence*

Act. Then, in December 2023, the European Parliament, the European Commission and the EU's 27 member countries reached an agreement on the *Artificial Intelligence Act*, paving the way for it to become the world's first comprehensive regulatory law in the field of AI. Moreover, in March 2023 the UK's Department for Science, Innovation and Technology published the W*hite Paper on Artificial Intelligence*, but without an exact date for legislation.

Ⅳ. Challenges Facing Scientific and Technological Talent

i. The Competition for Scientific and Technological Talent Is Becoming Increasingly Fierce

Talent is the first resource for innovation. With the world entering a period of reshaping scientific and technological patterns, various countries are expanding the introduction of talent, leading to intensified competition for this talent. By virtue of their dominant positions, developed countries continue to enhance their attractiveness to scientific research personnel and improve their competitiveness in increasing the flow of global scientific and technological talent. This is done through measures such as relaxing policies governing the migration of skilled workers, opening up higher education and setting up collaborative research projects. For example, in order to increase the number of skilled immigrants in the US, the US government revised the relevant provisions of the country's immigration law three times and lifted limits on outstanding high-tech talent. In addition to providing legal protection for the influx of scientific and technological human resources, the US government has also created a superior environment for scientific and technological innovation domestically with the aid of scientific and technological policies and innovation strategies, thereby making the country more attractive to high-tech talent. In 2023, Germany and France amended their *Immigration Laws* and relaxed the conditions for skilled immigrants to better satisfy their need for talent.

ii. The Global Distribution of Top Scientific Research Talent Is Too Concentrated

In October 2023, Stanford University released the "World's Top 2% Scientists" of 2023. This selected the world's top 2% of scientists from a total of nearly 7 million scientists worldwide, with scientists classified into 22 fields and 176 sub-fields. Countries that topped the list in terms of the number of top scientists included the US, China and Japan. Teams of scientists are mostly distributed among high-tech enterprises and scientific research institutes at universities. There is a big gap in the number of top scientists between the countries topping this list and other developing countries. Furthermore, according to the *Research on the Development of Global Digital Technology in 2023: Research Report on the Strength of*

Scientific and Technological Talent Reserve that was released by AliResearch and Zhipu AI in January 2023, global digital science and technology talent largely comes from scientific research institutions affiliated with the top universities in the US (such as Stanford University, Carnegie Mellon University and the University of California) as well as US tech giants (such as Google, Microsoft and IBM). Of the world's top 10 institutions in terms of high-level talent in digital technology, six are based in the US and four in China. The four Chinese institutions on this list are the Chinese Academy of Sciences (5th), Peking University (6th), Tsinghua University (9th) and Shanghai Jiao Tong University (10th). Comparatively speaking, the Chinese Academy of Sciences is a microcosm of the structure of China's reserves of digital science and technology talent and leads by a wide margin in terms of its talent base, with high-level talented persons accounting for just 3%.

iii. Losses of High-level Talent in Scientific and Technological Innovation Remain Serious

When it comes to talent in scientific and technological innovation, developing countries still face the problems of "not wanting to retain talent", "being unable to retain talent" and watching talent flow to developed countries. The governments and universities of developing countries have adopted multiple measures to provide excellent talent or reserves of talent with opportunities to study abroad and strengthen the cultivation of high-level international talent. However, a large amount of high-level, innovative talent cultivated by developing countries ends up working in other countries. To a certain extent, this has led to a waste of public education resources in developing countries, caused a significantly imbalanced distribution of high-level innovation talent between developed and developing countries, and greatly restricted the ability of developing countries to improve their scientific and technological innovation capacities. To this end, the governments and higher education systems of developing countries should reflect on the motivating factors behind such problems and take immediate and effective measures to mitigate the loss of talent. Meanwhile, the information asymmetry in the introduction of international, innovative talent is becoming more prominent. First, international, high-level talent is not able to be promptly and fully informed of information regarding open recruitment in the relevant countries. Second, it is difficult for developing countries to deeply and comprehensively know the true level of their talented persons, which then leads to a mismatch between their entry-level wages and academic competence, not to mention limited entry-level effectiveness.

Chapter Ⅲ
Artificial Intelligence and Digital Technology

The world has seen exceptionally active innovation in the fields of artificial intelligence (AI) and digital technology, which have in turn altered the pattern of global competition. The so-called large-model technology has triggered a new round of development boom for artificial general intelligence (AGI), and the converged network of communication, sensing and computing has become a new development trend; one that can reveal a path toward a deeper, more extensive immersive experience anytime and anywhere in the parallel virtual/real space.

Ⅰ. The AI Large Model

The AI large model, also known as the AI pre-training large model, embodies the meanings of "pre-training" and "large model". The combination thereof creates an AI paradigm in which models can directly support various applications with only a small amount of data fine-tuning—or even no fine-tuning—after the completion of pre-training on large-scale datasets. These models generally employ a multilayer neural network structure and are trained through advanced optimization algorithms and computational resources with strong generalizability, versatility and practicability, by which it's possible to achieve breakthrough performance in fields such as natural-language processing, computer vision and automatic speech recognition.

ⅰ. Development Trends and Regional Competitiveness

1. More Than 200 Large Models Have Been Released Globally, with the Number in China and the US Accounting for 90% of the World's Total

The Transformer network structure released by Google in 2017 is the source technology for the development of large models. Since then, large-model technology has made landmark technological breakthroughs in natural language understanding, computer vision, automatic speech recognition, etc., and has achieved leapfrog development in terms of model accuracy, generalizability and generalization ability.

Since 2018, large technology companies such as Google, OpenAI, NVIDIA, Meta and Microsoft have launched their own large-model technologies, and pre-trained large models

are gradually becoming mainstream research in the field of natural language processing.

China is a frontrunner in the development of large models. While the US led the rapid development of large-model technology in 2021, China has started a boom in large-model releases, gradually introducing a number of models that have had industry influence. Globally speaking, China and the US lead the global development of large models. Based on its advantage in algorithmic model research and development, the US ranks first in the number of large models it has introduced. According to *Large-model Map Research Report of Artificial Intelligence in China*, a document jointly released by the Institute of Scientific and Technical Information of China and the New-Generation Artificial Intelligence Development Research Center of the Ministry of Science and Technology, as of the end of May 2023 the US had released 100 large models with parameter sizes greater than 1 billion. China had released 79, and the global total of large-model introductions was 202. Thus, the number of large models in China and the US accounted for almost 90% of the number of worldwide total, placing China in the top echelon.

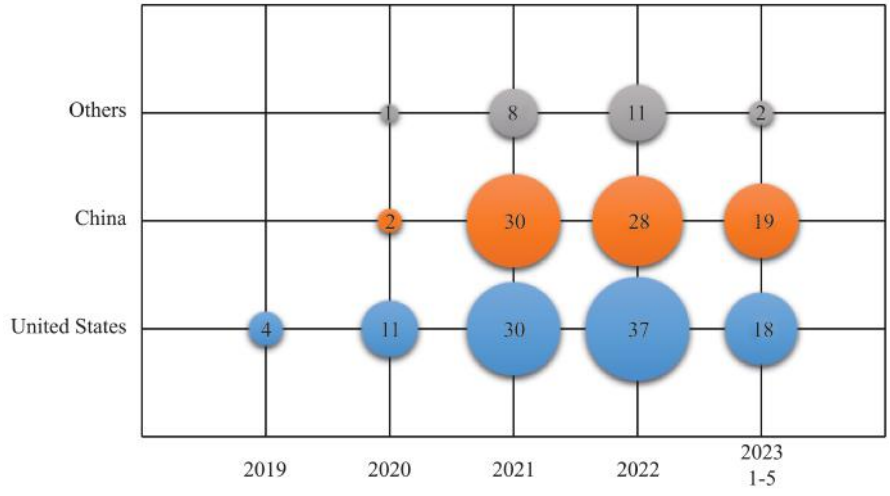

Figure 1 Global Distribution of Large Models①

(Source: *Large-model Map Research Report of Artificial Intelligence in China*, released by the Institute of Scientific and Technical Information of China)

2. The Large-model Market Size Exceeded USD 100 Billion Globally in 2028, and China's Market Exceeded RMB 100 Billion

As a general-purpose technology, the large model can play a prominent role in fields such as natural-language processing, computer vision, speech recognition, text recognition and recommendation systems. According to DAMOAI's estimate, the global large-model market will reach USD 21 billion by 2023 and USD 109.5 billion by 2028. In 2023, the size of

① The calculation standard is for large models with parameter sizes of 1 billion and more.

China's large-model industry will reach RMB 14.7 billion and then RMB 117.9 billion by 2028.

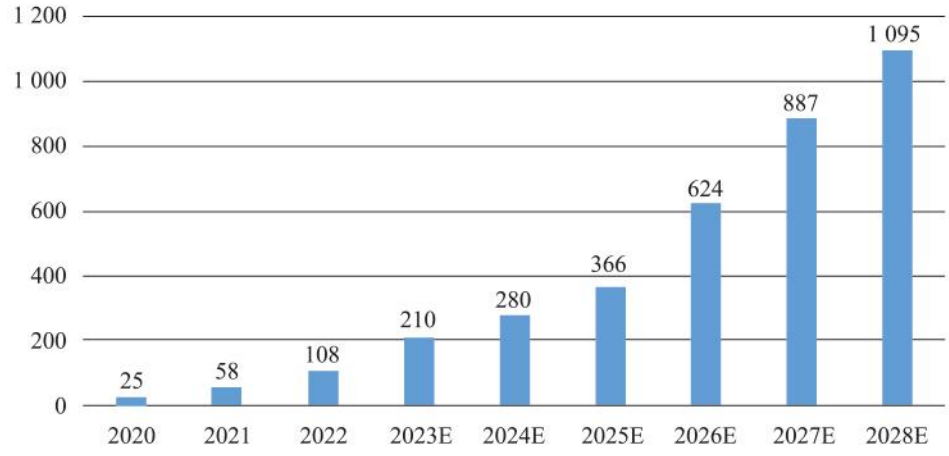

Figure 2 Global Large-model Market Size, 2020-2028 (in USD '00 Million)

(Source: *Research Report on the Innovation Value of AI Large Model Industry* by DAMOAI)

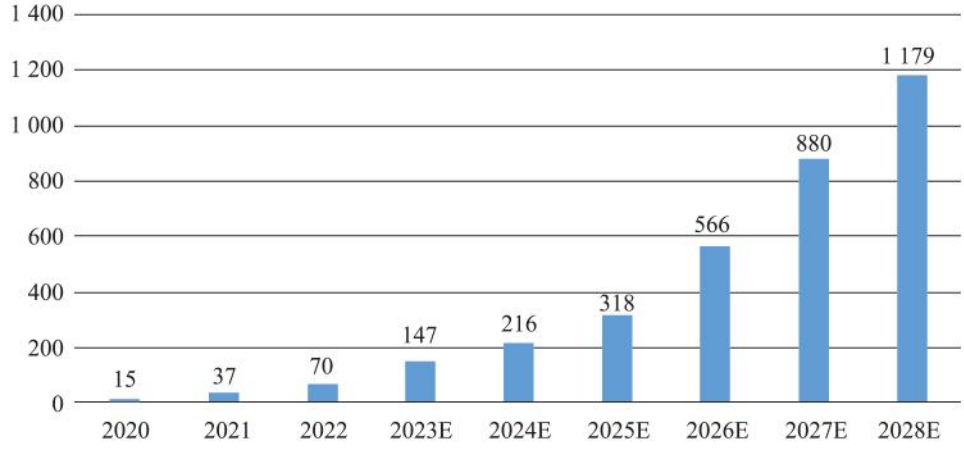

Figure 3 China's Large-model Market Size, 2020-2028 (in RMB '00 million)

(Source: *Research Report on the Innovation Value of AI Large Model Industry* by DAMOAI)

3. The Global AI Large-model Technology Enjoys Rapid Growth, and the Patented Technology Comes from Countries Such as China, the US, South Korea and Japan

As shown in the figure below, patent applications for AI large-model technology have increased significantly since 2018. In fact, the number of patent applications for AI large-model technology in 2021 approached 14,000. Overall, large-model technology is developing at an impressive rate. The technology is evolving constantly, and market exploration is extensive. Thus, it's expected that the number of patent applications will continue to grow.

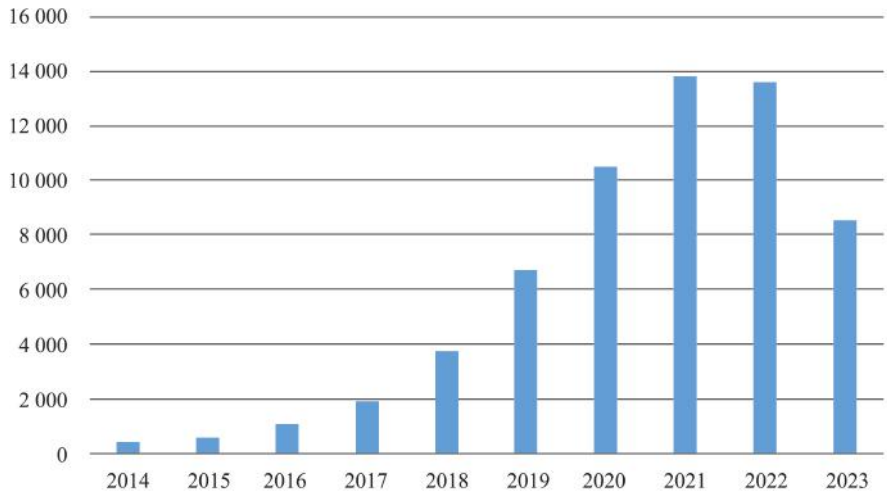

Figure 4　Global AI Large Model Patent Application Trends (Item)

(Source: PatSnap)

The most significant countries, in terms of AI large-model technology output, are shown in the figure below. China accounts for 58% of the total, and it, together with South Korea and Japan, accounts for approximately 70% of the global statistics. The US, meanwhile, accounts for 18% of AI large-model technology. Globally speaking, China, the US, South Korea, Japan, Germany and India rank among the top countries for patent output, demonstrating considerable technological capacity.

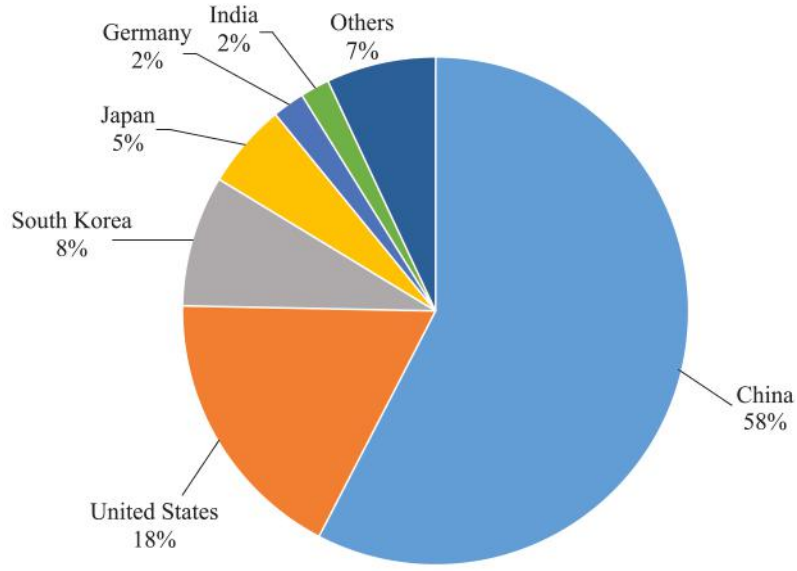

Figure 5　Geographical Distribution of the World's Major Contributors to AI Large Models

(Source: PatSnap)

ii. The Impact of Disruptive Technological Innovation

AI technology has been dramatically developed, as seen in the success of large models as well as the success of AI painting and ChatGPT. Thus, generative AI technology has ushered in an inflection point in development and has attracted a great deal of attention.

1. Large Models Drive Change in the Way Content Is Produced

The term "generative AI" refers to the methodology based on AI techniques such as large models and generative adversarial networks (GAN) to identify the functional laws of existing data and then generate relevant content through appropriate generalization capabilities, which can generate original content variants such as images, text, audio and video. ①

OpenAI released ChatGPT in 2022, and since then the world has seen a boom in generative AI. Many technology companies have launched generative AI models, products, related infrastructure and services. Large models have helped to realize diverse, high-quality, highly efficient content production, in the process becoming a force in content-production methods.

(1) Text Generation

Text-generation applications are generally found in four areas: Content continuation, text style migration, summary and title generation, and whole-paragraph text generation. Thus, there are broad prospects for personalized text generation and the related real-time text interaction.

Text generation based on NLP technology was an early application in the development of generative AI. The world's leading technology companies—including Microsoft and Xmind—have launched text-generation tools for copywriting, data analysis, presentation, mind mapping and others.

(2) Image Generation

The technical scenarios of image generation are classified as image-attribute editing, image localization and change, and end-to-end image generation. The application scenarios of the first two are image-editing tools, and end-to-end image generation is applied to creative image generation and functional image generation. The use of image-editing tools is extensive, and there are many related products. Creative image generation is generally presented in the NFT form, and functional images tend to be based on marketing posters and UIs, logos, model pictures and user-profile images.

(3) Audio Generation

Audio generation has become more common in daily life, but its application can be distinguished as either speech synthesis or music creation. Speech synthesis in turn encompasses the fields of text-to-speech (TTS) and speech cloning. TTS is more mature, at

① Internet Society of China, Global Generative AI Industry Research Report 2023.

least technologically, but it lacks emotional expression. Speech cloning is of great significance to the movie and animation industries, and therefore it merits attention. Music creation can be further subdivided into lyrics, composition, arranging, recording, mixing and other directions, and the creative process mainly relies on the Transformer model.

(4) Video Generation

Video generation is expected to be a scenario of medium potential for future cross-modal generation domains. Video generation corresponds to the three application scenarios of video attribute editing, automatic video editing and video part generation. Video attribute editing has been widely used in the field of video creation because it significantly enhances efficiency. Video automatic editing is mainly in the technical experimentation phase. The principle of video part generation is similar to that of image generation because it emphasizes the cutting of video into frames and, in turn, the processing of each frame. The technology is meant to improve the accuracy of modification and facilitate real-time modification.

(5) Digital Human

The term "digital human" refers to a comprehensive product that exists in the non-physical world (e. g., images, videos, live streaming and VR) and has multiple human characteristics. Digital human represents the transformation from low-density modalities such as text and audio to more information-dense modalities such as images, videos and real-time interaction. In the future, video and even metaverse fields will be important application scenarios for digital humans. In the field of generative AI, digital human generation can be divided into digital human video generation and digital human real-time interaction. Digital human video generation is one of the most widely used technologies, and real-time interaction is generally used for the visualization of intelligent customer service, placing more emphasis on real-time functionality.

2. Large Models Lead the Way in Digital Transformation①

(1) Large Models Promote Deep Integration of Industries Across Domains

Given the advantages of big data, big market and multiple application scenarios, AI has been incorporated into traditional industries such as transportation, medical care and manufacturing. Consequently, numerous business models have emerged. In the manufacturing industry, the large model can facilitate the automatic optimization of automobile design, modeling and other aspects. It can be used to create 3D models, and it can facilitate intelligent management through intelligent logistics and intelligent security. In the medical field, large models can realize the structure prediction of protein molecules, help physicians assimilate image reports and analyze case reports, and provide AI escort and interactive psychological counseling. In the financial field, the large model has given birth to digital

① China Academy of Information and Communications Technology, Large Model Governance Blue Report (2023).

employees to automate services and further optimize investment management and risk management with the help of AI customer service, AI investment advisors and AI finance. According to Accenture, AI applications are expected to bring USD 4 trillion in additional growth to the manufacturing industry in 2035, representing annual growth of as much as 4.4%.

(2) Large Models for Enhanced Public Services

The application of large models in the public sector is in full swing to improve the quality and efficiency of public services. Thirteen countries or regions such as the US, the UK, Portugal and Singapore have applied ChatGPT to internal government offices, public service delivery and other scenarios. According to a web-based questionnaire survey conducted by the Nomura Research Institute in Japan, the usage rate of ChatGPT in government departments reached 17.5%, second only to the telecommunication industry (32.8%) and the manufacturing industry (19.2%). In terms of market share, according to Prudential the market share of governments applying large models exceeds USD 10 million in 2022 and is projected to exceed USD 500 million in 2032, representing a CAGR of 45.8%. The introduction of large-model technology can significantly improve the efficiency of human-computer interaction. Moreover, the advantages of large models at the level of information collection, data analysis and language reshaping capabilities can effectively assist in integrating government's governance resources, improving governance structure, breaking down government organizational barriers and facilitating cross-departmental and cross-level collaborative governance.

3. Future Development of Large Language-model Products

(1) Continuous Exploration of the Generative Controllability of Large Models①

The question of how to establish a unified, controllable generation framework, self-detection of generated content and secondary modification of generated content should be further explored. The current models are generally text and image-based, so there are few 3D models. Taking the digital human as an example, the most difficult thing to achieve is the face. Even though there are many referable prototypes in reality, the data manifested by images can't support the requirements of 3D scenes. Recently, the appearance of the Magic3D model broke the deadlock of large-model application in 3D, but the insufficiency of data means it isn't yet possible to make the 3D model universal. In the future, video generation will be an area with great potential and commercial value, and consequently there will be dramatic growth in generative AI.

(2) Approach and Transcend Human Thinking②

The emergent capacity of the available large language models determines their basic

① IDC China, 2022 China Large Model Development White Paper.

② Source: InfoQ, Comprehensive Review of the Large Language Model 2023

performance with respect to logical reasoning. Relatively complex, rigorous and flexible logical reasoning and self-learning power are still the core challenges for most language models. The scientific interpretation of language models and their emergent power is also a major challenge for industry and research because interpretability equates to reproducibility and industrialization for such models.

Understanding human emotions through logical reasoning is a more advanced mode of human-like thinking. For example, some language models are able to make simple judgments about human emotions. The ability to understand and thereby create content and solutions based on emotional needs is now a high expectation in regard to language models, and accordingly it's a subject of pursuit among leading developers.

Ⅱ. Converged Network of Communication, Sensing and Computing

A converged network of communication, sensing and computing is a network that simultaneously possesses physical and digital space perception, ubiquitous intelligent communication and computing capabilities. Through the synergy and sharing of hardware and software resources in communication, sensing and computing, each element device in the network can achieve the deep integration and reciprocal enhancement of multidimensional perception, collaborative communication, and intelligent computing functions, thus enabling the network to employ a new type of closed-loop intelligent interaction together with the processing of information flow and wide-area intelligent collaboration. It could also provide support for typical application scenarios such as smart cities, smart transportation and smart homes.

We interpret the connotations of the converged network of communication, sensing and computing as described in the following:

Sensing resembles the human body's senses. Sensing refers to the perception of physical and digital multidimensional space, which contains two major parts: Network external perception and network endogenous perception. The former includes the perception of the electromagnetic environment (channel state, spectrum quality, electromagnetic interference, etc.) as well as the external physical environment (target motion detection and recognition, target imaging, etc.), and the latter includes the perception of service requirements (transmission rate, communication delay, arithmetic requirements, etc.) along with network physical and digital space state (network element equipment operation state and resource usage, AI training model library, digital twin network operation state, etc.).

Computing equates to the human brain. Generally, the term "computing" refers to fragmented, isolated network elements with computational capabilities dispersed throughout the network. However, in the converged network of communication, sensing and computing

it refers to the distributed ubiquitous intelligence that can be allocated and invoked collaboratively subsequent to enhanced sensing and communication.

Communication functions in a manner similar to the nerves of the human body. Communication is the carrier that empowers the sharing of multidimensional perceptual information among intelligent network nodes, distributed intelligent computation and other information interactions. It's also the basis for intelligent collaboration over a wide area of the network.

Communication, sensing and computing are deeply integrated and mutually enhanced. This converged network facilitates a new type of closed-loop information flow, i. e., intelligent interaction and processing through the deep fusion and reciprocal enhancement of cloud, edge and terminal multidimensional sensing, collaborative communication and intelligent computation. Thus, it supports the wide-area intelligent collaboration of the converged network of communication, sensing and computing. ①

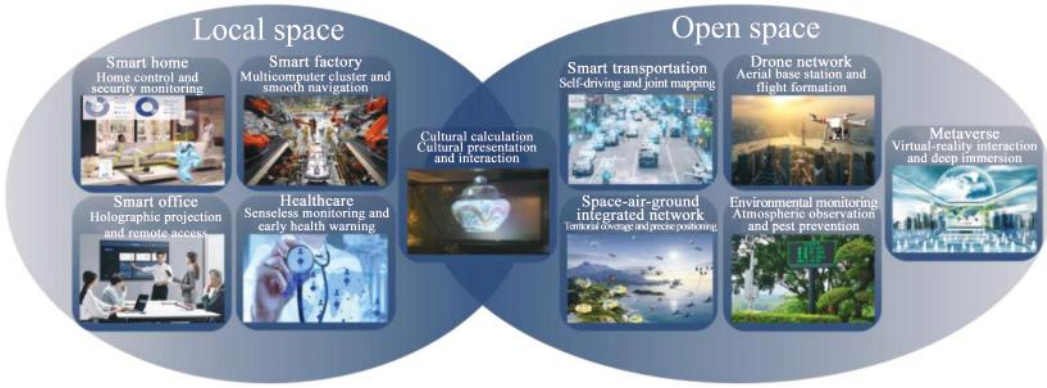

Figure 6 Typical Application Scenarios of the Converged Network of Communication, Sensing and Computing

i. Development Trends and Regional Competitiveness

1. The Converged Network of Communication, Sensing and Computing Is in Its Infancy, with Rapid Technological Development Led by China, the US and Europe

Academia and industry have in recent years studied the convergence technology involving communication, sensing and computing. In November 2020, China Mobile proposed an integrated framework for 6G communication, sensing and computing convergence at the World 5G Convention. Subsequently, countries undertook the R&D and planning of communication, sensing and computing converged network technology as shown in Table 1.

① Source: Frontiers in Communication, Sensing and Computing Converged Network Report (2021), China Institute of Communications, January 2022

Table 1 Developments in Major Countries in the Convergence of Communication, Sensing and Computing①

Country/Region	Event
China	The European Union, in June 2021, launched the latest round of the framework program of the Horizon Europe research cycle (2021-2027). It published a white paper on 6G vision with a view to maintaining Europe's leading position in the field of science and technology. The Smart Networks and Services Joint Undertaking, which is responsible for 6G research, explicitly takes the convergence of communication, sensing and computing as the signature technology of 6G, which has been a subject of focus among academics and standards organizations in various countries.
United States	The IMT-2030 6G Promotion Group established the Communication, Sensing and Computing Convergence Task Force in 2021, which is responsible for the 6G preliminary study of communication and sensing integration.
Europe	The US ComSenTer focuses on communication and sensing convergence technologies, including terahertz ultrahigh-speed communications and ultrahigh-precision imaging.

In the process of researching communication, sensing and computing converged network technology, some representative papers in the resource management research of communication, sensing and computing convergence have also emerged, as is shown in Table 4.

Table 2 Representative Papers in the Resource-management Research of Communication, Sensing and Computing Convergence②

Introduction	The Target or Related Work
Summarize the standard research progress of C-V2X and the C-V2X resource pool.	The centralized and distributed resource scheduling methods under LTE-V2X and NR-V2X are described, respectively.
An edge intelligence multisource data-processing scheme for autonomous driving in the loV is proposed.	Improve the overall system as well as the accurate inference rate of neural networks.

① Overview and prospect of communication-sensing-computing integration for autonomous driving in the internet of Vehicles, https://mp.weixin.qq.com/s/lsCXZaScNaLY6dJtq2YGCw

② Overview and prospect of communication-sensing-computing integration for autonomous driving in the Internet of vehicles, https://mp.weixin.qq.com/s/lsCXZaScNaLY6dJtq2YGCw

Continued

Introduction	The Target or Related Work
The network architecture of the next-generation IoV is proposed.	Content distribution, edge caching, computing offloading, and autonomous driving technology are analyzed in detail.
Compared with delivery to the cloud, MEC reduces the transmission distance and transmission delay.	An integrated platform is designed to solve the problem of resource deployment and management.
A system based on MEC is constructed, and an offloading algorithm is proposed.	To solve the problem of high traffic density in the Internet of Vehicles, manage and control the data offloading of V2X.
The mathematical model for task importance is established, and the task-offloading/sorting algorithm as well as the offloading algorithm based on Q learning are designed.	The energy consumption and delay of task offloading are optimized.
A distributed offloading strategy is proposed, whereby multiple collaborative nodes have a serial offloading. mode and parallel computing mode in the V2X scenario.	The optimization problem of system-delay minimization is established.

As Table 4 shows, research scholars at home and elsewhere have made progress in the resource management of communication, sensing and computing convergence. However, most of the existing related research focuses on the integration of bilateral capabilities such as communication and sensing, communication and computing, and sensing and computing. The means with which to achieve deep integration of the three is still in the conceptualization phase.

2. Communication, Sensing and Computing Converged Network Technologies Have Shown Rapid Growth During the Past Five Years

As Figure 15 shows, since 2019 the global patent application for communication, there has been remarkable growth in sensing and computing converged network technology. Statistically, the number of patent applications for this network technology exceeded 3, 000 as of 2022. Thus, the industry comprising communication, sensing and computing converged network technology is developing at a high rate. Innovation is constant, and the market is being explored intensively.

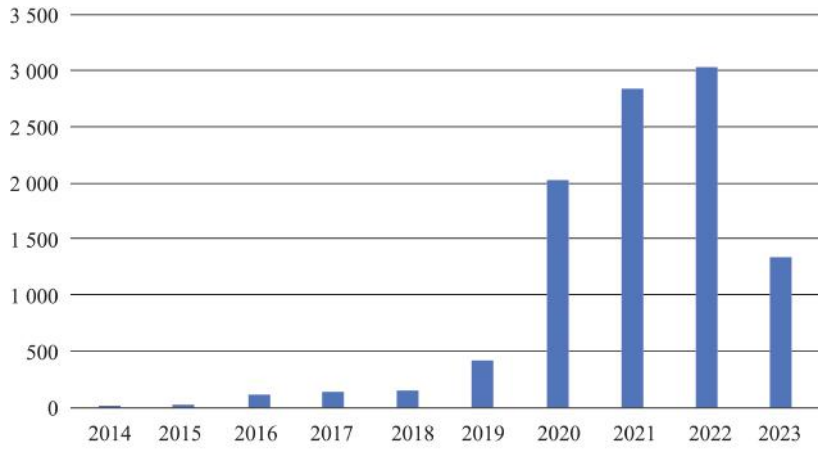

Figure 7 Trends in Patent Applications for Communication, Sensing and Computing Converged Network Technologies through 2023 (Item)

(Source: PatSnap)

3. Global Communication, Sensing and Computing Converged Network Technologies Originate Mainly in Asia and North America

The regions of output with respect to patented technologies for the communication, sensing and computing converged network are analyzed as shown in the figure below. Asia's output accounted for as much as 59.9%, of which China, South Korea and Japan have been the main patent-output regions. In global terms, China, the US, South Korea and Japan rank at or near the top in patent output, demonstrating their strong technological capacity.

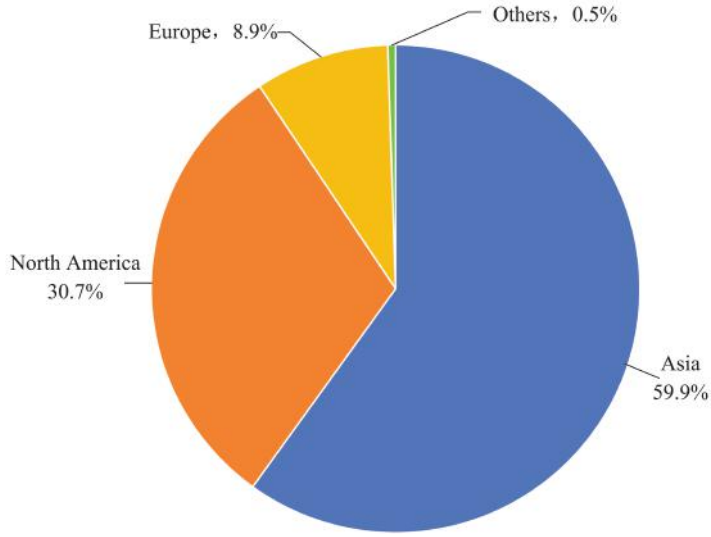

Figure 8 Regions with Communication, Sensing and Computing Converged Network Technology by 2023 (Item)

(Source: PatSnap)

ii. Impact of Disruptive Technological Innovation

Given the global commercialization of 5G, the industry has started systematic research on 6G. From mobile Internet to the Internet of things, and then to smart Internet of things, 6G will promote the construction of a universally smart human society, and meet the needs of new 6G scenarios such as super-energetic transportation, common-sense interconnection, holographic interaction, metaverse, precise medical treatment, smart industry, etc. 6G mobile information network needs to have new functions such as smart endogenous, multidimensional perception, and digital twin. Communication, sensing and computing converged network is emerging as the development trend of the new-generation mobile information network①.

1. Wireless Air Interface Technology

Wireless communication requires the flow of information from the transmitting device to the receiving device through the air (or the air interface). Thus, the wireless air interface is a technology that connects the end user to the base station through wireless communication. This process is affected by factors such as distance, obstacles and weather. Accordingly, the management and optimization of the air interface is an important aspect of the design of wireless communication systems.

(1) Wide-ranging Application Scenarios for Wireless Air Interface Technology

Wireless air-interface technology has many possible application scenarios. For example, in the intelligent grid, wireless air-interface technology can be used for data acquisition and monitoring so as to achieve remote management and control. In vehicle communication, wireless air-interface technology can be used for communication between vehicles and between vehicles and roadside facilities. In the area of industrial automation control, wireless air-interface technology can be used for communication and data exchange between devices. In smart healthcare, wireless air-interface technology can be used for communication and data exchange between medical devices. Wireless air interface technology can also be applied to public security, smart city and others.

Thus, the wireless air interface is available for a wide range of application scenarios. Moreover, prospects will increase with the continuous evolution and development of this technology.

(2) 6G Wireless Air Interface Technology Awaits a Breakthrough

Each previous generation of wireless communication technology relied on advancements in wireless air-interface technology to increase the rate of wireless transmission. In 2008, Dr. Erdal Arıkan, of Turkey, published the Polar code, which was adopted by the 3GPP in 2016

① Thoughts on 6G integrated communication, sensing and computing networks, https://mp.weixin.qq.com/s/W4EGDJD42l7VAo6volSlmA

as the 5G control channel coding standard. As a manner of precedent, in 1908 Marconi proposed the MIMO technique to resist the fading of signals. In 1995, Teledair enhanced the capacity of MIMO in the case of fading. In 1998, the Alcatel-Lucent Bell Labs established an experimental MIMO system. It took 20 years for 5G to adopt massive MIMO. Thanks to the advancements in large-scale integrated circuit technology and algorithms, 5G successfully achieved the implementation of the preceding theories.

The realm of 5G hasn't seen a breakthrough in wireless air-interface technology. 5G has applied the massive antenna technology and new channel coding techniques that have evolved over the years, but for 6G there is little in the way of promising wireless air-interface technology reserves. While Massive MIMO will continue to increase the number of beams, it isn't proportionally more efficient. Thus, the radius of the cellular area will shrink.

Spectrum expansion to incorporate millimeter wave, the adoption of non-cellular architecture and orbital angular momentum technology, the change from the passive avoidance of interference to the active elimination and use of interference and other ideas are certainly promising, but limitations remain. Moreover, it's difficult to achieve an obvious breakthrough in air-interface technology. Therefore, work on 6G must continue with respect to the wireless physical layer but must also pay attention to innovations in network technology.

2. High-precision Synchronization Technology for Collaborative Nodes

High-precision synchronization technology for collaborative nodes is a technology developed to serve synchronization needs with respect to multiple collaborative nodes in a distributed network. It relies on the premise that all nodes in a given network use the same time base, doing so through means of information interaction and collaborative work among multiple nodes. The purpose of this approach is to ensure the synchronization accuracy of collaborative operation and data transmission for every node in the network.

（1）Wide-ranging Applications of High-precision Synchronization Technology for Collaborative Nodes

Various application scenarios are being explored in regard to high-precision synchronization technology for collaborative nodes, including but not limited to:

Communications: Through the use of a high-precision synchronizer, it becomes possible to synchronize each node in the network and ensure the effective use of communication bandwidth and efficient scheduling of media resources.

Finance: In financial transactions, the time stamp of the transaction is very important, and the high-precision synchronizer can provide high-precision and highly reliable clock synchronization to ensure seamless financial transactions.

Manufacturing: Automated production lines in the manufacturing industry require strict synchronization, and high-precision synchronizers can provide accurate, stable synchronization services for the production line to improve production efficiency and quality.

Energy: For energy prevention and control systems, the use of high-precision synchronizers

can ensure the synchronization between energy equipment, making sure that the system's data acquisition, control and monitoring functions can be achieved.

Space: In space fields such as satellite communications and space exploration, high-precision synchronization technology can be used to realize integrated communications between space and the ground, and accurate synchronized transmission of ground-based observation data.

The high-precision synchronization technology for collaborative nodes can also be applied to the Internet of vehicles, the Internet of things, edge computing and others. With the continuous development of this technology and the continuous expansion of its application scenarios, high-precision synchronization technology for collaborative nodes will be used in more fields.

(2) Challenges That Await the Technology

The high-precision synchronization technology for collaborative nodes suffers from the problems of time-synchronization accuracy, network security, cross-domain synchronization, energy consumption, fault detection and recovery, as outlined below:

Time-synchronization accuracy: Although there are already some high-precision synchronization techniques, the accuracy of these techniques is affected by a variety of factors such as network delay, clock skew, data-processing speed, etc., Consequently, it's difficult to achieve wholly accurate synchronization.

Network security: The high-precision synchronization technology for collaborative nodes requires close cooperation and information interaction between each node, so it's open to interference and attack by malicious parties. The question of how to ensure network security is an important issue.

Cross-domain synchronization: In a distributed system, nodes can be distributed in different geographical areas and different networks. Consequently, the manner in which to achieve cross-domain synchronization is a challenge. The accuracy and reliability of cross-domain synchronization are difficult to ensure due to transmission delays and the quality differences that can occur between networks.

Energy consumption: The high-precision synchronization technology for collaborative nodes requires large amounts of computation and information interaction, and therefore consumes large amounts of energy and computational resources. The question of how to reduce energy consumption is also an important issue.

Fault detection and recovery: In the collaborative-node high-precision synchronization system, the failure of a node may affect the synchronization accuracy of the entire system. Therefore, it's necessary to quickly detect and recover the fault so as to ensure the system's normal operation.

In view of the above problems, it's necessary to further study and improve the high-precision synchronization technology for collaborative nodes to improve their synchronization accuracy and reliability while bolstering network security, fault detection and recovery.

Chapter Ⅳ
Information and Communications Technology

Ⅰ. 5G/6G Wireless Technology

5G is the fifth-generation cellular network technology after 4G LTE. It was first launched in 2019, with Verizon taking the lead in commercial deployments in April of that year. Unlike 3G and 4G that came before it, 5G isn't just an incremental technological advancement but a true leapfrog technology. Speed is among the greatest differences between 5G and its predecessors. It offers theoretical speeds of up to 10 gigabits per second, more than 30 times faster than 4G LTE Advanced's theoretical maximum speed of 300 Mbps. This technology also uses higher frequency bands than previous generations and is deployable in low-band, mid-band or high-band millimeter waves from 24 GHz to 66 GHz. Thus, it provides much faster data-transfer speeds along with greater bandwidth capacity.

The sixth generation of cellular network technology, known as 6G, will ultimately replace 5G. It's expected to be available in 2030 and promises even higher speeds than its predecessors. There are already reports of 206.25 gigabits per second achieved in a lab environment in China. This technology will use higher frequency bands than 5G, operating in the 30 to 300 GHz millimeter-waves up to 300 to 3,000 GHz radiation. Additionally, it will provide better coverage and improved reliability due to its wider range of spectrum usage①.

ⅰ. Development Trends and Regional Competitiveness

1. Countries Are Substantially Increasing Their Support for Scientific Research on 6G

Countries are bolstering their investment in the field of 6G through measures such as the issuance of policies, the formation of research teams, the construction of public research facilities and the initiation of 6G research projects, seeking to propel cutting-edge technological research on 6G in academia and industry. Moreover, countries are taking

① An glimpse of the difference between 5G and 6G, https://baijiahao.baidu.com/s?id=1763679341664885174&wfr=spider&for=pc.

industry alliances or working groups as leverage for accelerated development of the 6G industry.

Table 3 Development of 5G/6G Wireless Technology in Major Countries①

Country/Region	Event	Alliance
China	The *14th Five-Year Plan for the Development of the Information* and *Communications Sector and the 14th Five-Year Plan for the Development of the Digital Economy* were issued in 2021.	IMT-2030 (6G) Promotion Group
	The Ministry of Industry and Information Technology, in 2023, issued the *Regulations on the Radio Frequency Allocation of the People's Republic of China*, being the first country to allocate the 6, 425-7, 125 MHz frequency band for 5G/6G systems and organize research on 6G.	
United States	Three pieces of communications-oriented legislation-the *FUTURE Networks Act*, the *Understanding Cybersecurity of Mobile Networks Act* and the *American Cybersecurity Literacy Act*-were passed to ensure that the United States could maintain a leading position in the next generation of communications technology.	Next G Alliance (a trade organization dedicated to managing 6G development in North America)
	In 2022, the U. S. Department of Defense established a 6G R&D center, thereby launching three projects-Open6G, Massive Multi-Input/Multi-Output (MIMO) from MHz to GHz project, and the Spectrum Exchange Security and Scalability project-with a total budget exceeding USD 7 million.	
Europe	In 2021, the European Union initiated a 6G flagship research project called "Hexa-X" to create unique 6G use cases and scenarios, develop foundational 6G technology and define a new structure for 6G intelligent networks.	6G Smart Networks and Services Industry Association (6G-IA)
	In October 2022, the European Union launched the second phase of its 6G flagship project, called Hexa-X-II.	
	In December 2022, the Smart Networks and Services Joint Undertaking (SNSJU) passed its *Research and Innovation (R&I) Work Programme for* 2023-2024.	

① Global 5G/6G Industry Development Report (2022-2023), Telecommunication Development Industry Alliance, March 2023.

Continued

Country/Region	Event	Alliance
South Korea	The *Future Mobile Network Research and Development Promotion Strategy to Take the Lead in the Age of the 6G Generation* was introduced in 2020, making South Korea the first country to realize the commercialization of 6G.	6G R&D Strategy Committee
	In 2021, the Ministry of Science and ICT developed the "6G R&D Implementation Plan".	
	In 2023, South Korea released the *K-Network* 2030 *Strategy*.	
Japan	In 2020, Japan proposed a series of strategic goals, including key technological breakthroughs in 6G by 2025, deploying 6G networks by 2030 and pursuing at least a 10% share of 6G technology patents.	Beyond 5G Promotion Consortium
	In 2023, the Ministry of Internal Affairs and Communications in Japan earmarked JPY 66.2 billion to fund the National Institute of Information and Communications Technology in its effort to support research on 6G wireless networks.	

2. The Global Volume of Academic Research Applications in the 6G Wireless Technology Industry Is Increasing

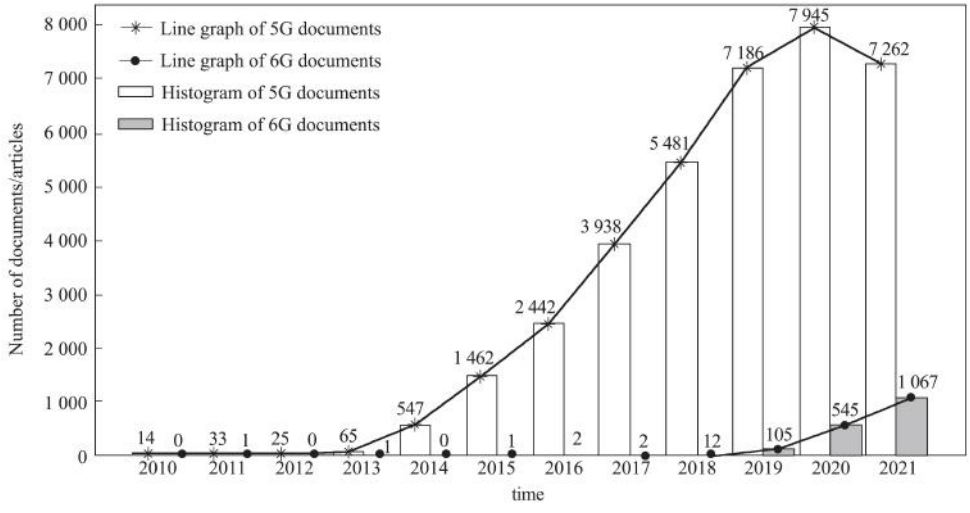

Figure 9 Global Distribution of 5G/6G Documents①

① Sha, Z., 6G knowledge-system construction: Academic knowledge mining and its on-demand application for whole domain and whole scenario, September 2023.

Based on the above graph, it's evident that the academic research on 6G kicked off in 2018 and witnessed a swift surge from 2019 to 2021, entering a phase of remarkable acceleration. In 2021, the number of documents has reached 1,067 articles. Academic research is expected to maintain the momentum of rapid growth in the future. However, it's still in the early stages. In order to better understand the future development trends of 6G, it's beneficial to refer to the distribution trends of 5G documents and then compare, analyze and forecast the distribution trends of 6G in the future.

Research on 5G began to appear in or around 2010, but from 2013 to 2019 the effort increased exponentially. However, the growth rate slowed after 2019, reaching its peak in 2020 with a substantial amount of 5G documents, totaling 7,945 articles. Given the aforementioned data, it can be said that the development cycle from the initial stage to the peak generally spans approximately eight to 10 years. Since 2020 there has been a downward trend in the number of documents, suggesting a transition from a gradual decline to a steep decrease in distribution.

3. Global 6G Wireless Technology Has Shown a Trend of Swift Development in Recent Five Years

As Figure 2 shows, global patent applications for 6G wireless technology have become more numerous since 2019. In 2021, applications for patents of 6G wireless technology approached 10,000. Generally, the 6G wireless technology industry is advancing. The technology is evolving, and the market is expanding.

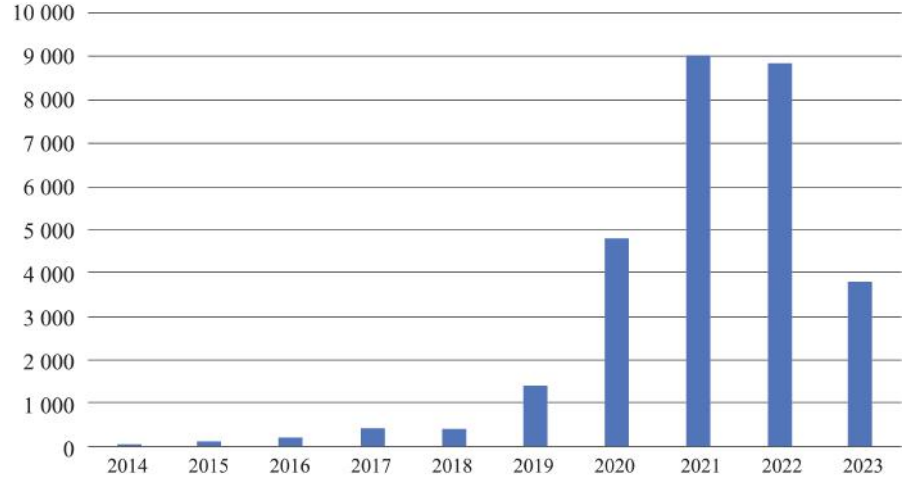

Figure 10 Trend in Patent Applications Related to 6G Wireless Technology by 2023 (Item)

(Source: PatSnap)

4. Asia and North America Are the Main Contributors to 6G Wireless Technology

The output regions of global 6G wireless technology are herein analyzed. As Figure 3 shows,

Asia accounts for 75.8%, of which China, South Korea and Japan are the major output areas in Asia. China, the US, South Korea, Japan and Sweden rank among the top countries in terms of patent output, demonstrating their impressive technical prowess in this field.

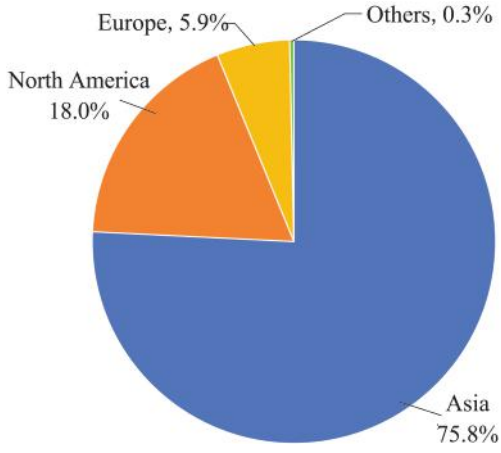

Figure 11 Regions with 6G Wireless Technology by 2023 (Item)

(Source: PatSnap)

ii. Impact of Disruptive Technological Innovation

The key technologies for 6G can be categorized into three technological fields: Wireless communication, wireless networks and network architecture. These technologies generally include 10 major technology directions: New network architecture, native AI, integrated sensing and communication, heterogeneous converged network, digital twin network, extremely large-scale MIMO, new wireless transmission, endogenous security, space-air-ground integration and the new, passive Internet of things. ①

The report uses space-air-ground integration and digital twin networks as disruptive technologies.

1. Space-air-ground Integrated Network

The space-air-ground integrated network, which is characterized by "global coverage, ubiquitous access, on-demand services, and security and credibility", is an important evolutionary direction of 6G in the future. The mission is to build a three-dimensional network structure that has a terrestrial network as the foundation along with an air-based network (including communication-navigation-remote sensing-integrated satellites) and a space-based network for supplementary and extended components, thereby achieving a space-air-ground integrated rich communication network across different geographical regions,

① China Mobile does the utmost to develop 6G technology to help digital economy development, http://www.xinhuanet.com/info/20230920/d29ef19a87df4d10aebc7a88bc574698/c.html.

airspaces and maritime areas, meet the requirements of wide-area intelligent connectivity and global ubiquitous seamless access, and achieve unified and efficient resource scheduling and network management and control. This kind of network could offer additional capacity such as global continuous communication in time and space, secure and highly reliable communication, regional high-capacity communication and highly mobile end-to-end information transmission within a three-dimensional, wide-area space. Thus, it has great importance in the enhancement of emergency response capabilities, national security, national welfare and economic development. The space-air-ground integrated network architecture is depicted in Figure 3.

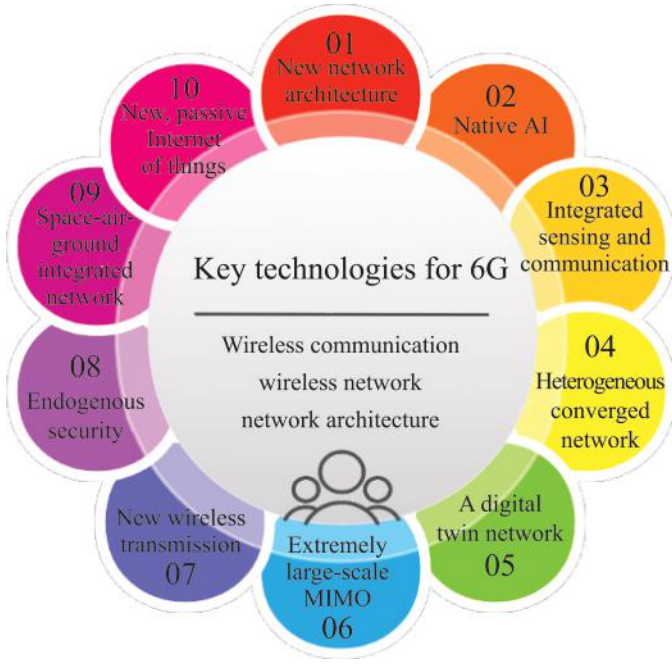

Figure 12 6G Wireless Technology

The space-air-ground integrated network, given significant communication advantages such as wide coverage, minimal environmental impact and high disaster tolerance, can extend to multiple dimensions such as space, air, land and sea without being restricted, so as to enhance the reliability and security of communication links. With the future collaborative networking of 6G high-, medium- and low-orbit satellites, the space infrastructure and ground infrastructure will gradually achieve deep integration through interconnection and complementary convergence so as to provide higher speeds, improved service quality and greater reliability while offering users uninterrupted communication services. Concurrently, satellite communications costs can be remarkably reduced through the scale effects of the cellular communications sector, which facilitates the promotion of satellite communications equipment and services among public users and provides ubiquitous, intelligent, synergistic and efficient communication services.

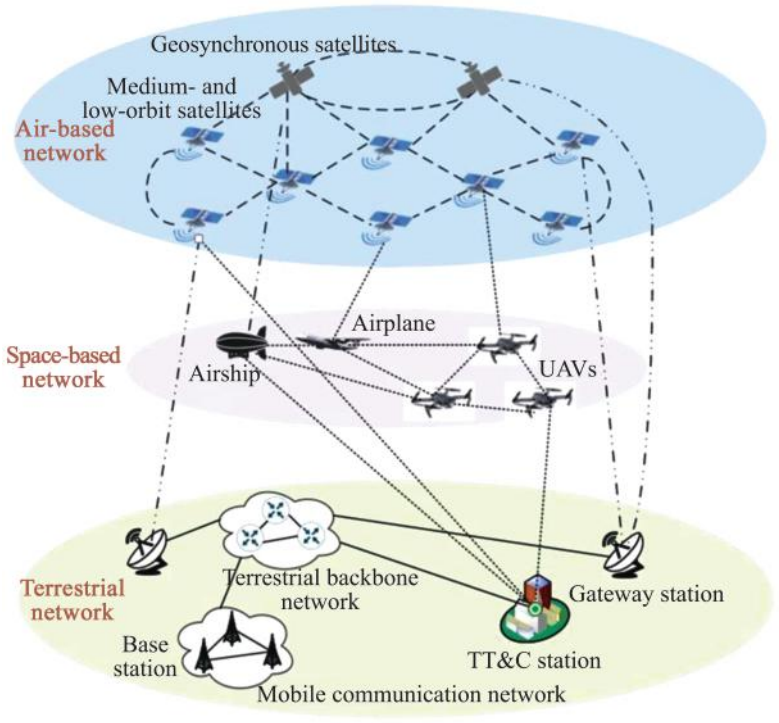

Figure 13 Schematic Diagram of 6G Space-air-ground Integrated Network Architecture①

(1) Vast Market Potential for Satellite Communication

Multiple countries worldwide have proposed their own satellite constellation plans, totaling 69,937 satellites by July 2023. Specifically, the Starlink constellation plan operated by the US-based company SpaceX has the most satellites—42,000—accounting for 60.05% of the total. Next comes China's Guowang (GW) Project, with 12,000 satellites and a share of 18.58%.

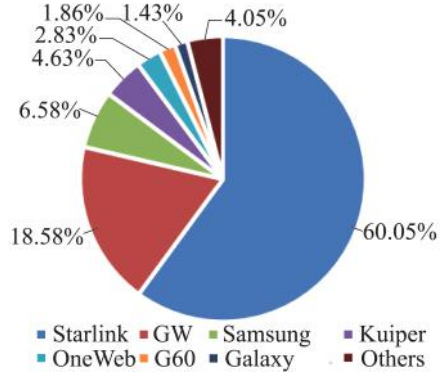

Figure 14 Proportion of Number of Satellites of Global Constellation Plans
(Source: Public information, collated by Pacific Securities)

Morgan Stanley has estimated that the per-satellite Starlink cost ranges from USD 500,000 to 1 million. (According to the official website of NASA, the curb weight of a satellite is approximately 260 kg.) When the median of USD 750,000 per satellite is considered, Starlink will generate approximately USD 31.5 billion in market value. The designed service life of a Starlink satellite is

① 6G Network Architecture White Paper, China United Network Communications Limited Research Institute et al., June 2023.

approximately five years. Starlink commenced the construction of its satellite constellation in late 2019. By the following year, 833 satellites had been launched, representing a value of approximately USD 625 million. It's projected that satellite replacements will begin in 2025. China's satellite manufacturing costs are relatively high. According to the prospectus of Chang Guang Satellite, satellites of similar quality to Starlink have a cost of approximately RMB 50 million. Based on the current satellite manufacturing costs, it will result in an incremental market of approximately RMB 649.6 billion.

Given the launch of new satellites to replace those that have reached the end of service life, and considering that satellite manufacturing costs will gradually decrease to a level comparable to those of Starlink, it's estimated that by 2030 there will be a cumulative market space of approximately RMB 312.2 billion.

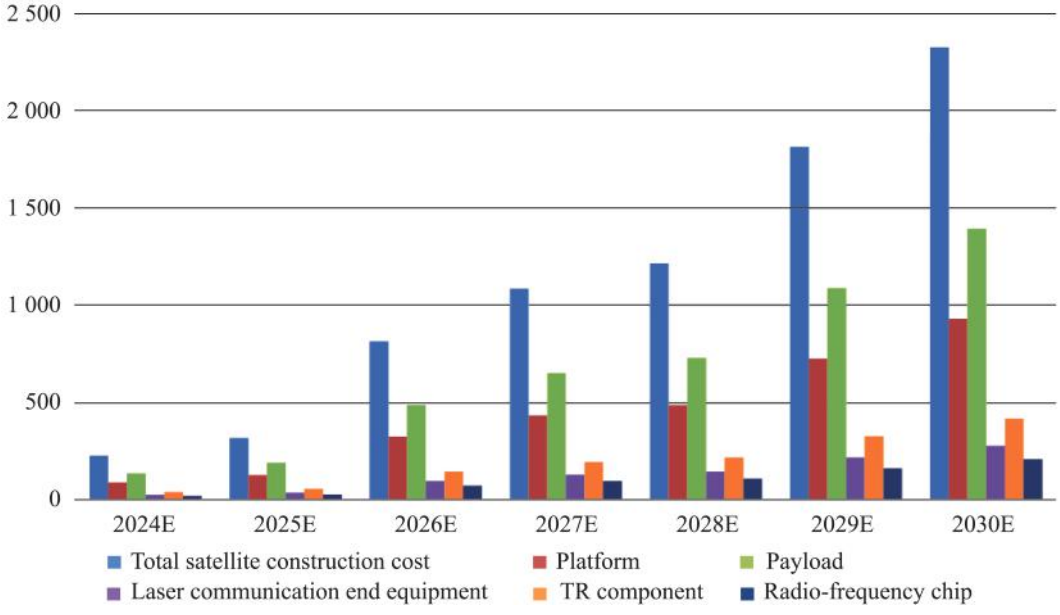

Figure 15 Measurement and Calculation of Market Space of Global Low-orbit Communication Satellites from 2024 to 2030 (in RMB '00 Million)

(Source: Collated by Pacific Securities)

(2) Limited Frequency Band Resources and Fierce Competition

Currently, the principle for applying to the International Telecommunication Union for satellite communication frequency is "first come, first served". When the ITU receives an application for a frequency band, it holds the application for a certain period in order to conduct spectral coordination and assessment. If no other party submits an application for the same frequency band within the reservation period, the applicant will be granted the right to use that frequency band. When multiple applicants want to launch and operate satellite communication systems within a specific frequency band, the first applicant will have priority

in obtaining the right to use this frequency band. Once an operator applies for a low-orbit constellation and communication frequency band, it's required to launch one satellite within seven years and operate it successfully for 90 days. Thus, 10% of the total number of satellites should be launched within two years. Fifty percent should be launched within five years, and after seven years all of the applied satellites should be in operation. In other words, the operator has a total of 14 years to complete the building of the entire constellation.

According to a spectral allocation devised by the International Telecommunication Union, satellite communication can use 11 wireless frequency bands within the range of 1 to 110 GHz. Traditional satellite communication generally uses the C band ranging from 4 to 8 GHz, and the new low-orbit constellation employs the Ku and Ka bands. Taking SpaceX's Starlink as an example, the first phase primarily uses frequency bands distributed across the Ku, Ka and Q/V bands, totaling approximately 18.1 GHz. The combined bandwidth of the Ku, Ka, and Q/V bands is 54 GHz. Altogether, Starlink occupies approximately 33.5% of those frequency bands. In the second phase, it generally uses the Ku and Ka bands, occupying a total of 6.4 GHz, which represents 33.7% of the total bandwidth of the Ku and Ka bands. Thus, the frequency-band resources are severely limited. ①

2. Digital Twin Network

The "digital twin" concept was initially introduced by Professor M. Grieves in the United States. It's defined as a three-dimensional model, including physical products, virtual products and the link between them. With the development of digital twin technology and its applications in production, manufacturing and other various industries, the digital twin technology is also gaining attention and research in the field of communication networks. A digital twin network creates a real-time mirror image of the physical network that can enhance the systemic stimulation, optimization, validation and control capabilities that are absent in the physical network, thereby assisting in the deployment of new network technologies and dealing with network problems and challenges more efficiently.

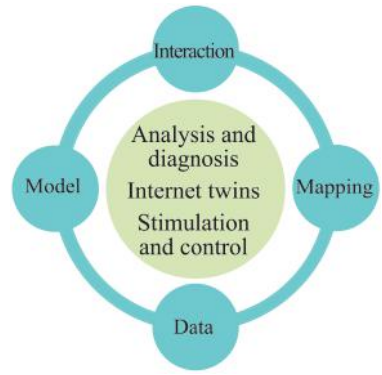

Figure 16 Schematic Diagram of Digital Twin Network②

① Communication Network Integration of Air and Ground: The Future Isn't Far, Pacific Securities, September 2023.

② A digital twin network, https://baike.baidu.com/item/%E6%95%B0%E5%AD%97%E5%AD%AA%E7%94%9F%E7%BD%91%E7%BB%9C/61826076?fr=ge_ala.

（1）Extensive Scenarios and Rapid Development in Digital Twin Applications

Data from the WEF indicates that digital twin applications in public services and public management account for more than 50% of the global digital twin city projects, and consequently they surpass other areas. The penetration rates of community development, as well as intelligent architecture and environment also exceed 40%, which are expected to experience impressive growth in the future.

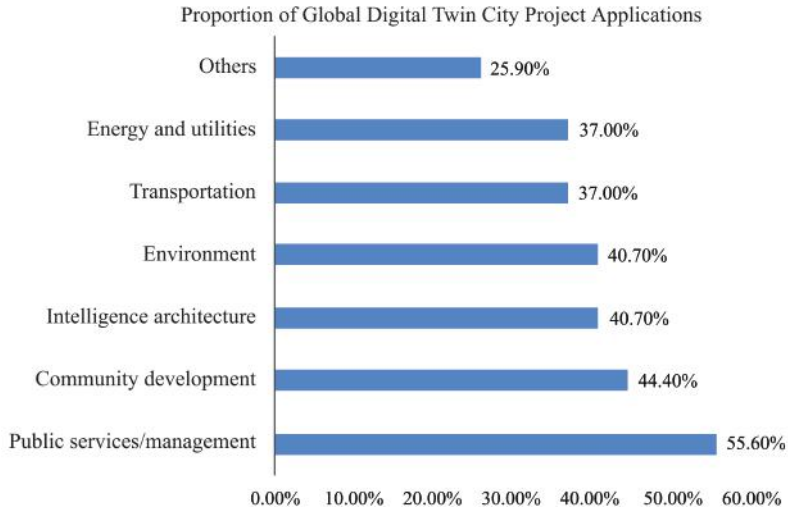

Figure 17 Proportion of Global Digital Twin City Project Applications①

（Source: WEF）

（2）The Massive Digital Twin Market

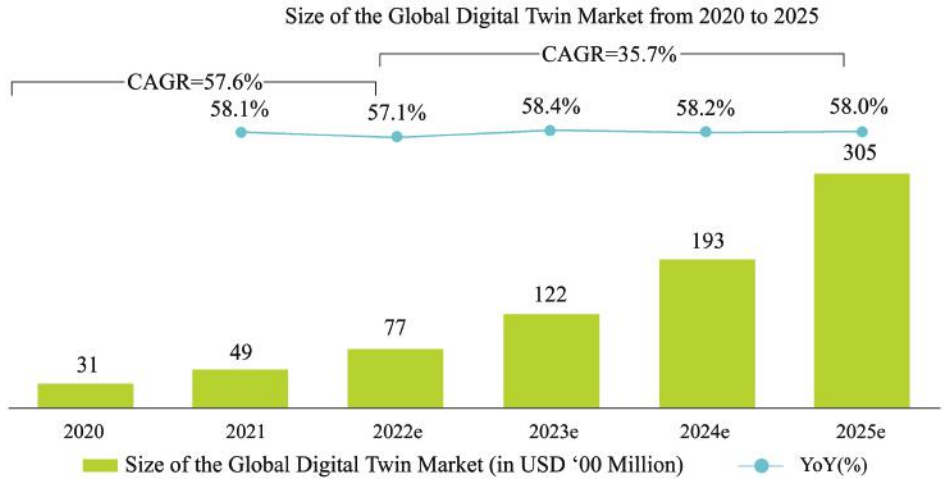

Figure 18 Global Digital Twin Market Size from 2020 to 2025

① Digital Twin World White Paper (2023), Digital Twin World Enterprise Alliance, April 2023.

Based on data from the CAICT, the digital twin market has great potential for growth and development. In 2022, the global digital twin market size reached USD 7.7 billion, an increase of 57.1% year on year, and the CAGR from 2020 to 2022 was 57.6%. It's expected that the global digital twin market size will maintain a high growth rate with a market size of USD 30.5 billion by 2025 and a CAGR of 35.7% from 2022 to 2025. ①

Ⅱ. Optical Communications Technology

Optical communication is a method of communication using optical waves as the transmission medium. It's characterized by advantages such as high communication capacity, long transmission distance, low signal interference and resistance to electromagnetic interference, which collectively make it the primary method of information transmission worldwide. Based on the needs of different transmission media, optical communication can be divided into atmospheric laser communication and fiber-optic communication. Atmospheric laser communication is a form of laser communication that uses the atmosphere as its transmission medium. Fiber-optic communication, however, is a communication method that uses light waves as the information carrier and optical fiber as the transmission medium.

The spectrum range available for optical communications technology includes infrared, visible light and certain ultraviolet bands. Unlike radio-frequency communication, which requires spectrum allocation, the frequency bands used in optical communication are considered as unlicensed spectrum. No authorization is required for the use of such frequency bands.

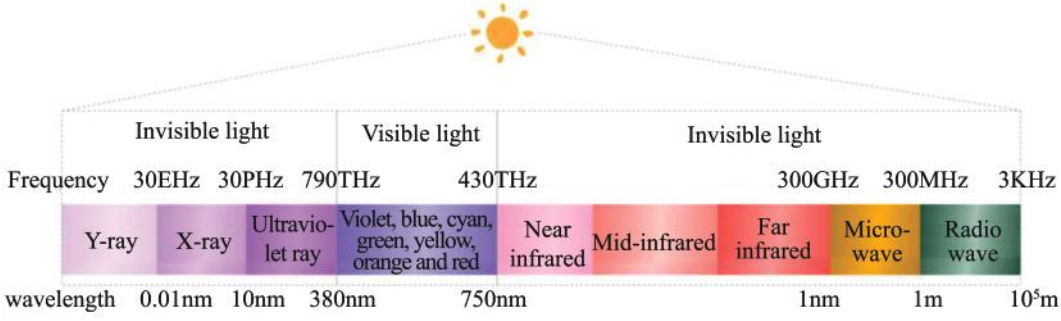

Figure 19 Schematic Diagram of Optical Communication Spectrum Resources

(Source: CSDN)

① Digital Twin Industry Research Report 2023, https://baijiahao.baidu.com/s?id=1774549106950003177&wfr=spider&for=pc.

ⅰ. Development Trends and Regional Competitiveness

1. Emerging Market Boom and Flourishing Optical Communications Sector

With the swift advancement and accelerated market penetration of information technologies such as cloud computing, big data, the Internet of things and artificial intelligence, emerging markets worldwide are surging in popularity. In 2020, for example, the overall revenue of the downstream sector in the optical communications sector witnessed significant growth, primarily driven by four major emerging markets. Significantly, pan-entertainment played the most prominent role. Its revenue share is expected to rise from 48% in 2020 to 55% in 2025. The pan-entertainment scenario, driven by user demand, demonstrates strong overall growth, of which ultrahigh-definition video holds the largest overall share. However, in terms of growth rate, VR/AR, live streaming and cloud gaming exhibit even faster growth. Additionally, the life and business scenarios experience relatively notable growth, chiefly influenced by policies. Among these scenarios, smart education and smart healthcare exhibit higher growth rates compared to other scenarios. ①

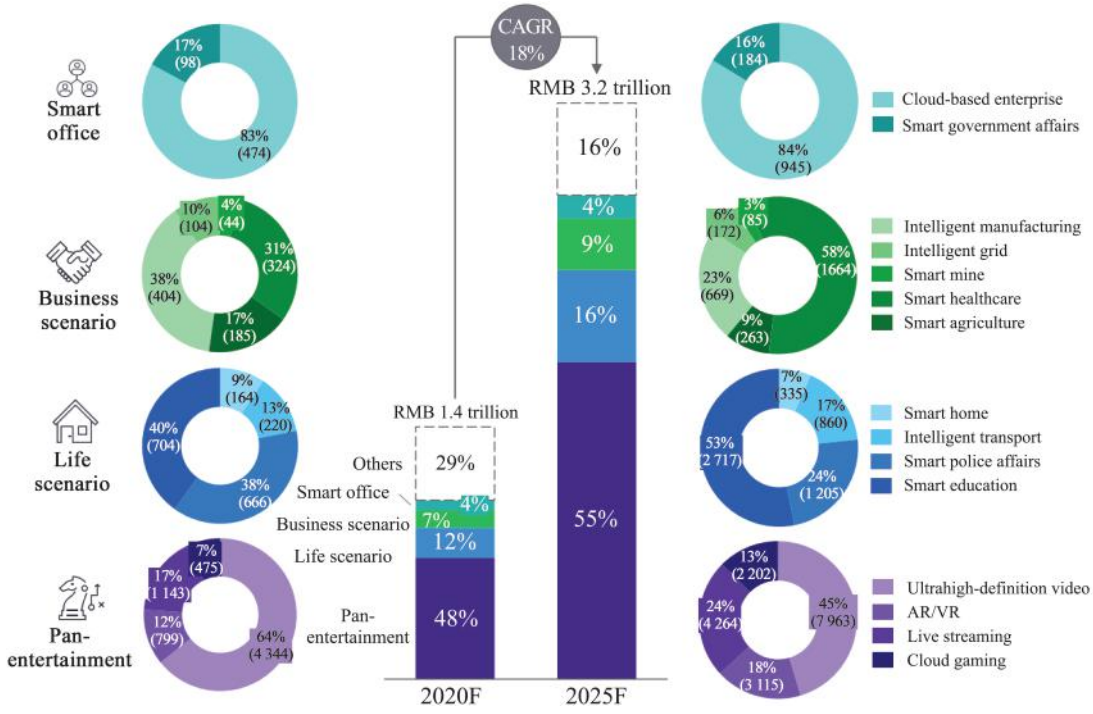

Figure 20 Flourishing Global Fixed-line Optical Communication Market Driven by Various Emerging Markets

Source: EY

① Ernst & Young, *Optical Communications White Paper 2021*.

2. Surging User Base and Connected Devices with "Fiber to the Home" Becoming the Trend

Globally, the total number of Internet users has increased from 3.9 billion in 2018 to 5.3 billion in 2023, with a compound growth rate of 3.5%. The global Internet user base shows a growing tendency. In the Asia-Pacific region, the percentage of Internet users in relation to the regional population has risen from 52% in 2018 to 72% in 2023, with a growth rate of 3.8%, which is higher than the global level. Research data indicates that the growth rate of connected devices (a compound annual growth rate of 10%) is significantly greater than that of Internet users (a compound annual growth rate of 6%).①

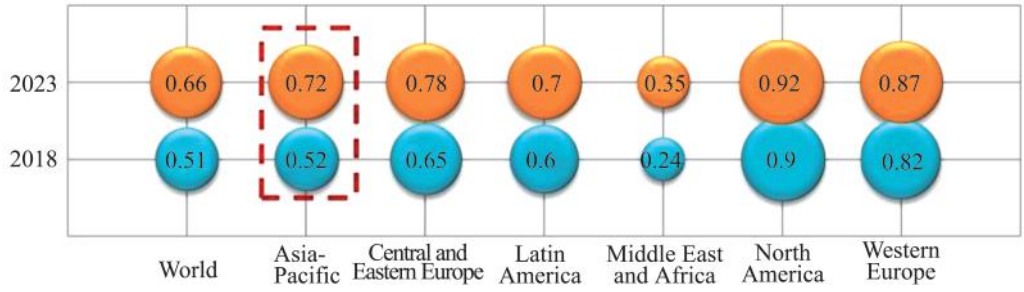

Figure 21 Percentage of Internet Users as a Proportion of Regional Population from 2018 to 2023

(Source: Cisco)

The growth of connected devices is chiefly caused by M2M applications, which include intelligent meters, video surveillance, healthcare monitoring, transportation and package or asset tracking. M2M applications have made a considerable contribution to the increasing number of connected devices. By 2023, M2M connections will account for half the population of connected devices. The continuous increase in the number of connected devices is closely associated with the growing average number of connected devices per person, which has risen from 2.4 in 2018 to 3.6 in 2023 globally. In the Asia-Pacific region, it has increased from 2.1 to 3.1. Specifically, the countries with the greatest numbers of connected devices per person in 2023 are the United States (13.6), South Korea (12.1) and Japan (11.1).

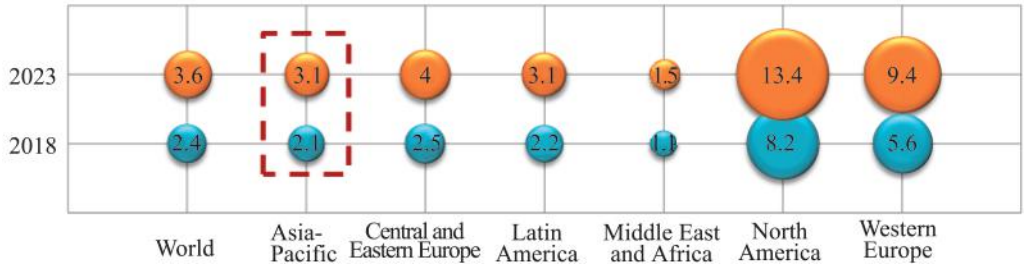

Figure 22 Number of Connected Devices Per Person from 2018 to 2023

(Source: Cisco)

① Cisco Annual Internet Report (2018-2023).

Currently, the construction cost of optical fiber coverage (HP) in major countries worldwide has witnessed a slump due to the large-scale deployment of networks and the maturation of new plans. Compared to the early stages, the average cost per unit has dropped by 60%. Meanwhile, optical fiber has emerged as the digital infrastructure for the global economy and social development. Therefore, governments are enacting policies to encourage the development of gigabit Ethernet based on optical fiber.

Compared to conventional copper-based electrical communication, optical communication that uses optical fiber as the medium offers notable advantages in terms of transmission speed, network bandwidth, signal attenuation and communication costs. It caters to the high-speed, high-reliability and long-distance requirements of information dissemination in response to the explosive growth of data traffic. According to Cisco, the average fixed broadband speed in the Asia-Pacific region is expected to reach as high as 157.1 Mbps by 2023, which is 2.5 times higher than the 62.8 Mbps of 2018. Japan, South Korea and Sweden are the leaders in terms of broadband speed, primarily due to their extensive FTTH deployment.

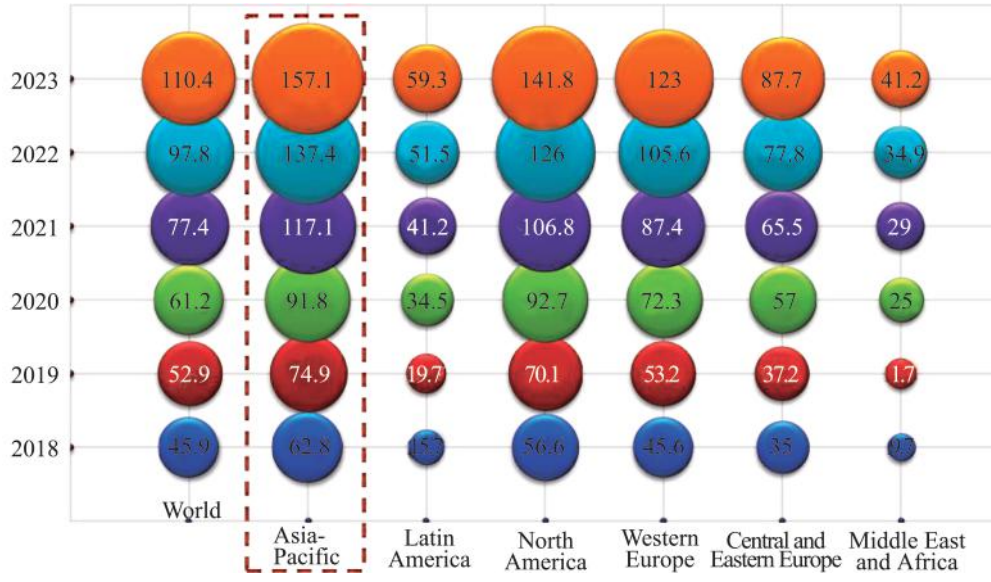

Figure 23 Fixed Broadband Speeds from 2018 to 2023 (Mbps)

(Source: Cisco)

3. Surging Patent Applications with Asia as the Key Technological Contributor

The following figure shows the development trends of the optical communications sector worldwide by examining patent data. Evidently, there has been considerable technological

innovation in the optical communications sector during the past two decades. In 2004 there were just 24,425 patent applications, but by 2022 the number had surged to 41,465. Evidently, the overall trend of patent applications in the optical communications sector is one of stable growth. Currently, as information technologies such as cloud computing, big data, the Internet of things and AI advance, the expectation is that the number of patent applications in optical communications technologies will continue to expand.

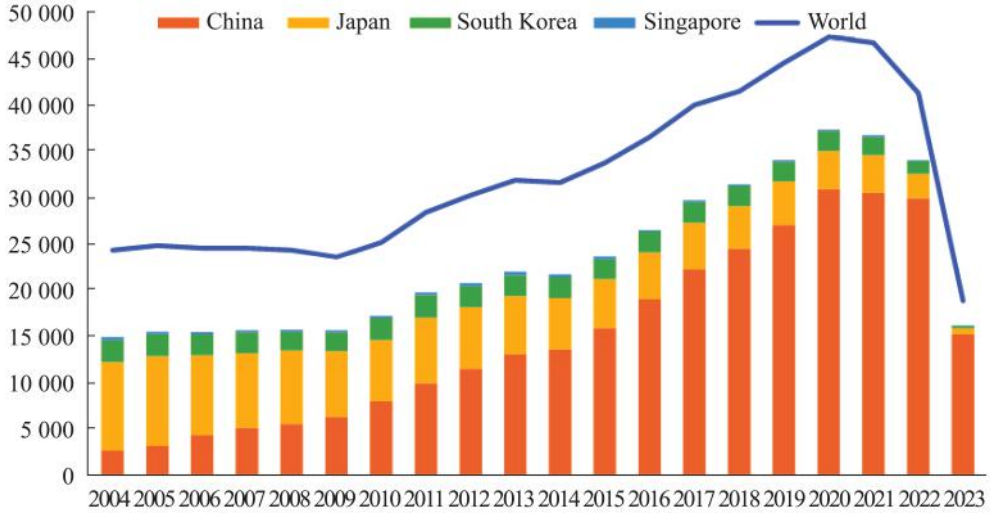

Figure 24 Trend in Global Patent Applications Related to Optical Communication (Item)

(Source: PatSnap)

As shown in the above chart analyzing global optical communications sector patent distributions, China holds the largest number of patent applications of any country, representing approximately 34% of the global total. This significantly surpasses other countries and makes China the leading technology source in the global optical communication field, as well as the largest producer of optical modules and optical devices. Meanwhile, Japan comes in second, with patent applications in the optical communication field accounting for 30% of the global total. South Korea and the United States rank third and fourth with contributions of 17% and 6%, respectively. As a result, Asian countries, notably China, Japan and South Korea, exhibit strong technological competitiveness and innovation capability in the global optical communication field, with China leading the charge.

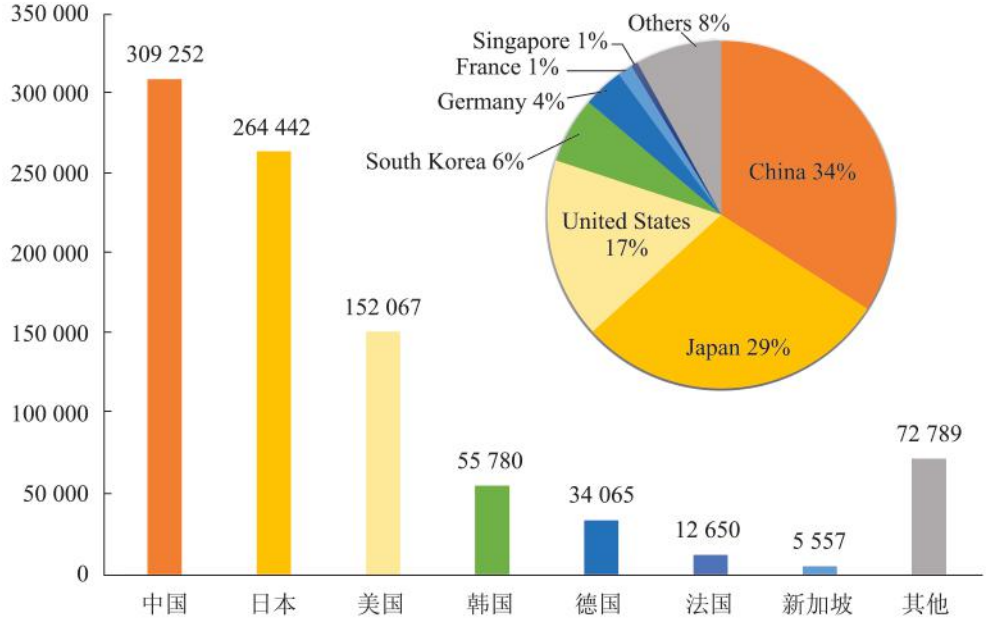

Figure 25 Geographical Distribution of Major Technology Contributors in the Global Optical Communication Field

(Source: PatSnap)

ii. Impact of Disruptive Technological Innovation

Optical communications technology is evolving globally and in China, and technological innovation in this field is significant when it comes to the digital transformation of daily life. Currently, visible-light communication serves as an innovative mode that combines lighting and communication, effectively complementing existing wireless radio-frequency communication methods. F5G, also known as the fifth-generation fixed network, is defined by the European Telecommunications Standards Institute (ETSI). Its features generally involve enhanced fixed broadband (eFBB), full-fiber connection (FFC) and guaranteed reliable experience (GRE) as the means to promote the evolution of FTTH to ubiquitous optical connectivity. Consequently, visible-light communication and full-fiber networks are considered disruptive technologies in recent years.

1. Visible-light Communication

Visible-light communication (VLC) uses visible light sources such as LEDs to transmit information by modulating the intensity of the light emitted by light sources at a high speed, which is imperceptible to the human eye. The received light signals are then converted into electrical signals using photoelectric converters such as photoelectric detectors (PDs) to obtain information. It's a wireless communication method that integrates lighting and communication. VLC serves as an innovative mode that combines lighting and

communication, thus complementing existing wireless radio-frequency communication methods. ①

Grantham Pang, of the University of Hong Kong, proposed the concept of visible-light communication in 1999. Subsequently, a research team led by M. Nakagawa at Japan's Keio University proposed an access scheme for LED-based visible-light communication. Since then, VLC technology has become a research hotspot for academia and industry. Indoor VLC research was initiated in Japan. In 2000, scholars such as Tanaka and Nakagawa from Keio University in Japan elaborated on the concept of VLC②. Subsequently, in 2003, Japan established the Visible Light Communication Consortium (VLCC), which quickly grew into an international organization③. The following year, Japan's Ministry of Land, Infrastructure, Transport and Tourism achieved visible-light transmission at a speed having an order of magnitude of 10 Mbit/s. ④

(1) Global First LiFi Standard Published, Enabling Prospects for Commercialization of Visible-light Communication

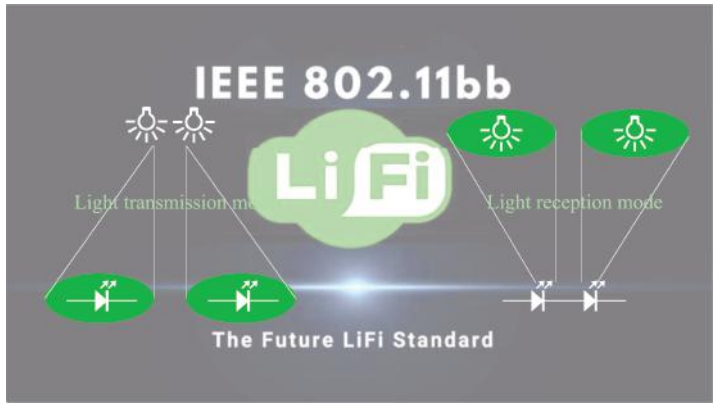

Figure 26 Spatial Reuse Defined by IEEE 802. 11 bb Optical Communication Standard⑤

The Institute of Electrical and Electronics Engineers (IEEE), in July 2023, ratified the IEEE 802. 11 bb standard, which defines the physical-layer specifications and system architecture for wireless communication using light waves. This new standard sets the

① China Mobile. 6G Visible-Light Communications Technology White Paper.

② Takana Y., Haruyama S. & Nakagawa M., Wireless optical transmissions with white colored LED for wireless home links. [C] //11th IEEE International Symposium on Personal Indoor and Mobile Radio Communications. London: IEEE, 2000.

③ Chen, Y. & Yang, H., China's indoor visible-light communication status and development trend, Optical Communications Technology, 2015, 39 (3): 50-52.

④ Komine T. & Nakagawa M., Performance evaluation of visible light wireless communication system using white LED lightings [C] // ISCC 2004. Ninth International Symposium on Computers and Communications. Washington: IEEE Computer Society, 2004: 258-263.

⑤ Part 7 Optical Communications of IEEE P802. 11 bb.

foundation for the widespread adoption of visible-light communications technology and paves the way for the interoperability of LiFi systems with the successful WiFi standard. Ratification of the standard was concluded in June 2023.

An analysis of global patent application trends in the field of visible-light communication reveals that the patent applications in this field during the past decades can be divided into two phases. Prior to 2010, the growth trend of patent applications was relatively stable, with the number of annual applications less than 500. However, after 2010, there was explosive growth in the number of patent applications related to visible-light communication. The main reason for this trend can be attributed to the following factors: Before 2010, VLC faced a bottleneck in transmission speed due to limitations in modulation bandwidth. Consequently, the overall growth in patent applications was somewhat slow. However, this bottleneck was quickly overcome in 2010 when a team at the Heinrich Hertz Institute in Germany achieved a communication speed of 513 Mbit/s, setting a world record and applying for the related patent EP2425557B1. Afterward, the record for transmission speed continued to be broken. In 2013, the number of patent applications surged to 1,000, and in 2017 it reached 1,711. With the release of the world's first LiFi standard, the visible-light communications sector is currently seeking commercialization opportunities and is poised for the next round of growth.

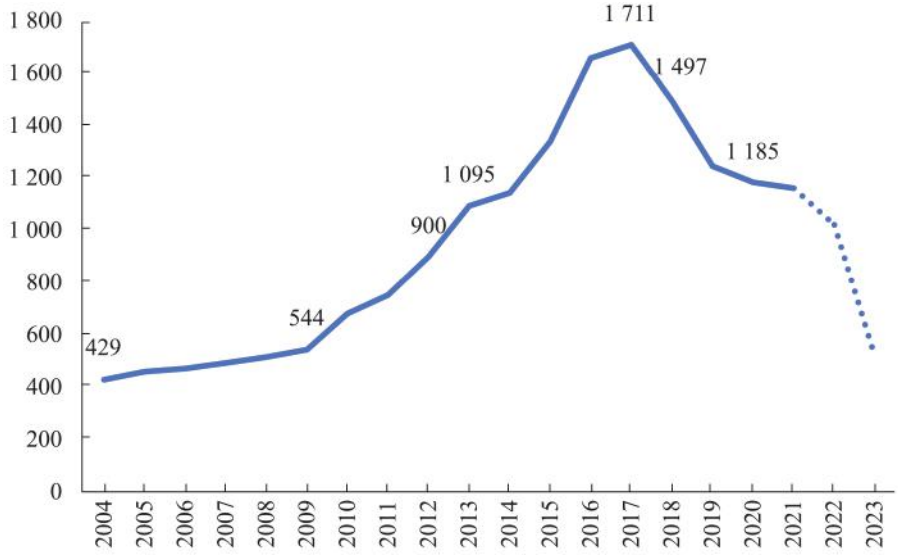

Figure 27 Trend in Global Patent Applications Related to Optical Communication (Item)

(Source: PatSnap)

(2) Challenges Faced by Visible-light Communication with Potential for Industrial Application Incubation

Visible-light communications technology is expected to meet important requirements in 6G, such as traffic density and user experience data rate, while improving network performance in terms of peak data rate, network energy efficiency and positioning accuracy.

However, it faces significant challenges in channel modeling, devices, transmission and networking. According to the analysis by China Mobile, the research time sheet for visible-light communications technology is depicted in Figure 35. Overall, it's projected to achieve industrial application incubation by 2030.

Currently, the channel modeling for different scenarios in visible-light communication lacks optimization and application testing in real-world working environments. Most high-performance key devices are still in the pilot stage in laboratories, and there is a lack of mature industrialized devices. Additionally, this technology needs to combine the characteristics of high-performance visible light devices with those of visible light channels. It should form a wireless visible-light, converged, heterogeneous network along with traditional radio-frequency communications (such as medium- and low-frequency, millimeter-wave and terahertz), to support continuous high-rate services in mobile scenarios. It's also important to establish a complete standard system for visible-light communication devices in order to foster industry synergies. Another challenge for the industrialization of visible-light communication is the miniaturization and integration of systems.

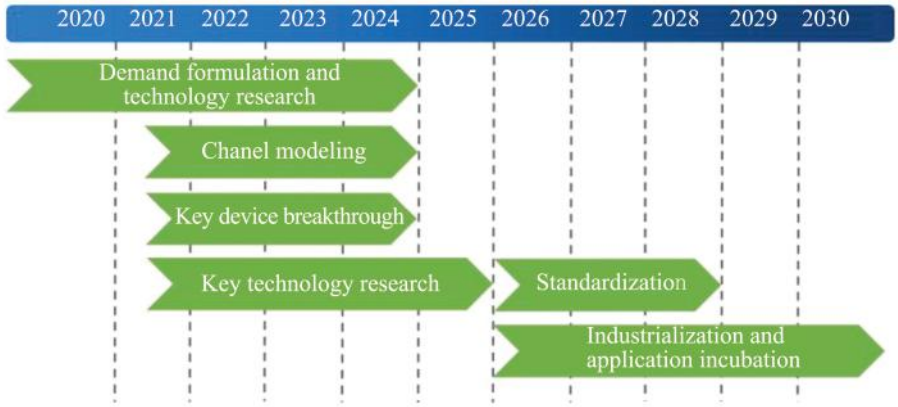

Figure 28 Research Time Sheet for Visible-light Communications Technology

2. The Fifth-generation Fixed Network

The European Telecommunications Standards Institute (ETSI), in December 2019, established the F5G Industry Specification Group (ISG) to further define the fifth-generation fixed network technology (ISG F5G). It has defined three major features of F5G, including enhanced fixed broadband (eFBB), full fiber connectivity (FFC) and guaranteed reliable experience (GRE). The purpose of F5G is to achieve an all-optical network, with representative technologies such as 10GPON, Wi-Fi 6, 200G/400G and next-generation OTN. Technologically supported by F5G gigabit optical fiber, it will propel humanity into a new era of "ultrafast connectivity" and "ubiquitous optical connectivity".

（1）Accelerated Upgrading of All-optical Network Coverage with FTTR Building a High-quality All-optical Base

The industry has proposed a new generation of all-optical networks, known collectively as FTTR, for the purpose of achieving seamless coverage of gigabit optical broadband network capabilities that can reach users and business terminals. The FTTR all-optical network is a technology based on the P2MP architecture, which extends optical fiber to every room, enabling gigabit or higher coverage throughout the entire household. It plays a crucial role in constructing high-quality information infrastructure for residential and enterprise broadband networks. FTTR provides stable whole-house gigabit coverage without blind spots. Moreover, it supports seamless roaming, thus providing an all-optical base for digital home applications.

Thus, the industry has reached a consensus on the development and building of FTTR. This consensus is shared by more than 100 operators worldwide, including (86 provincial operators in China and more than 20 overseas). Tens of millions of residential users around the world have subscribed to FTTR. Leading operators in China such as China Unicom Hebei are able to accrue more than 2, 000 FTTR users per day.

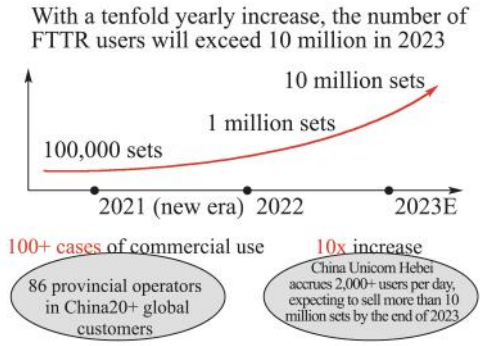

Figure 29　Research Time Sheet for Visible-light Communications Technology

(Source: Huawei)

（2）The East-to-West Computing Resource Transfer Project Drives Data Mobility and Facilitates the Development of Computing Power Network

Given the rapid development of generative AI, the volume of data generated in the coming years is expected to increase tenfold and massive bandwidth requirements will be released. Foundation models drive computing power to the cloud, and a new mode of intelligent cloud-computing services has been created, including power generation and transmission for use in computing.

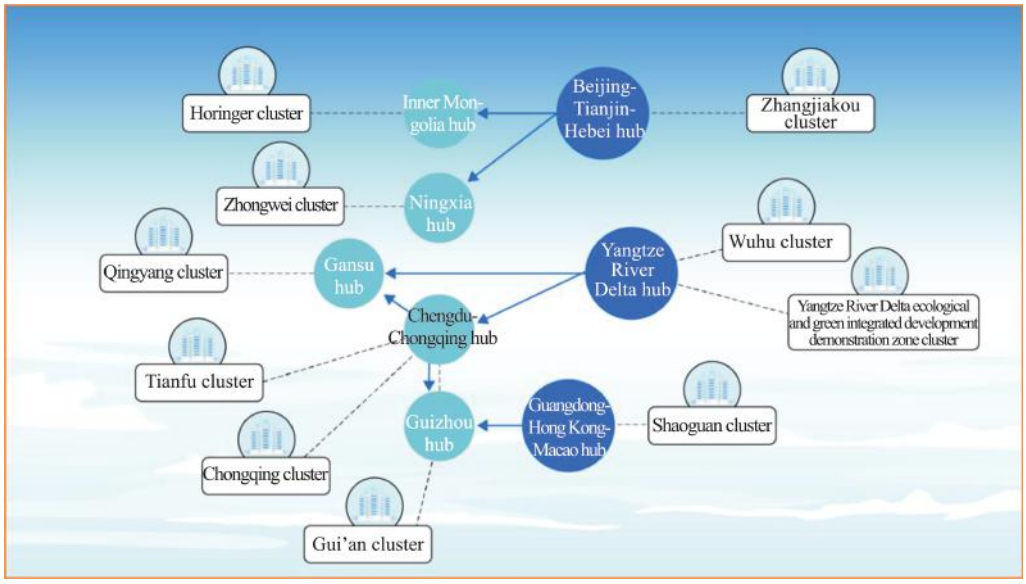

Figure 30　Computing Power Network of the East-to-West Computing Resource Transfer Project

（Source：Huawei）

The National Development and Reform Commission, the Cyberspace Administration of China, the Ministry of Industry and Information Technology, and the National Energy Administration, in 2022, jointly issued a notification approving the building of a national computing hub in eight regions: Beijing-Tianjin-Hebei, the Yangtze River Delta, the Guangdong-Hong Kong-Macao Greater Bay Area, Chengdu-Chongqing, Inner Mongolia, Guizhou, Gansu and Ningxia. Additionally, a plan was approved for the development of 10 national data-center clusters. China has proposed the "east-to-west computing-resource transfer" project as the means to establish a new computing power network system that integrates data centers, cloud computing and big data. The project intends to guide the orderly flow of computing power demand from the eastern regions to the western regions, optimize the layout of data centers, and promote collaborative synergy between the eastern and western parts of the country.

The computing power network serves as a crucial foundation for driving the deep development of the national "east-to-west computing-resource transfer" project. The project will enable the cross-domain flow of data and computing power, facilitating industrial advancement and balancing regional development. Additionally, it's estimated to save 12 billion kWh of electricity annually, effectively utilizing surplus wind and solar power, promoting energy conservation and emission reduction while contributing to the achievement of the carbon peaking and carbon neutrality goals.

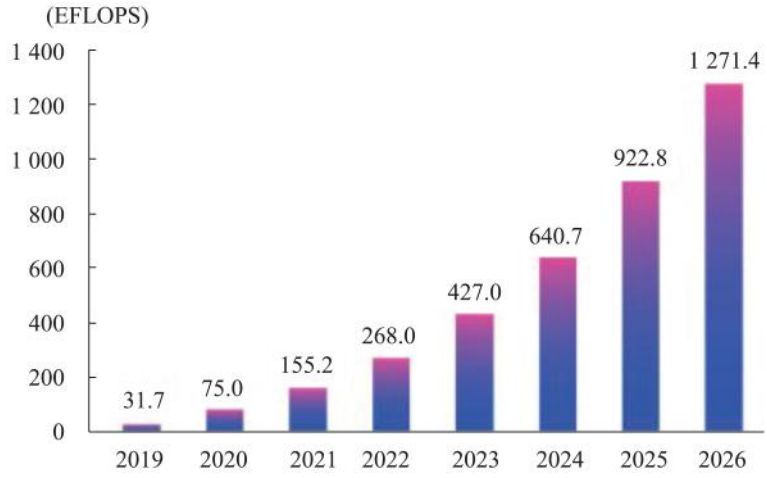

Figure 31 Development of Intelligent Computing Power in China

(Source: China Intelligent Computing Industry Alliance)

According to data from the Ministry of Industry and Information Technology, by the end of 2021, data centers in use in China have more than 5.2 million standard racks in terms of general computing power. The average utilization rate exceeded 55%. With respect to intelligent computing power, according to the Guidelines for Innovation and Development of Intelligent Computing Centers, China's intelligent computing power size experienced rapid growth in 2022, reaching 26.8 ExaFLOPS (EFLOPS), surpassing that of general computing power. It's projected that the compound annual growth rate of China's intelligent computing power size will reach 52.3% in the next five years.

Chapter Ⅴ
Healthcare and Biomedicine

Biomedical technology is an important part of healthcare, and accordingly it has a significantly positive impact on people's wellbeing. In recent years, as life science research has continued, a series of emerging technologies closely related to people's lives and health are flourishing, the application of AI-developed pharmaceuticals, organ chips and other technologies is accelerating, and life science and other disciplines-including big data-are extending their influence. Biomedical technology is now the core of the healthcare sector's development effort, providing continuous support through innovation.

Ⅰ. AI Pharmaceuticals

Traditional drug research and development involves a complex system. After the discovery of the lead compound through large-scale screening, repeated in vitro, animal and in-vivo experiments are required for testing and optimization until the molecular structure is shown to be safe and efficacious so that it can be approved for marketing. This field, hitherto based on scientific testing, is still dependent on the personal experience and creativity of pharmacologists. Consequently, it hasn't been able to overcome problems such as long cycles, high costs and low success rates. From research and development to the marketing of innovative drugs, it will take billions of dollars and a span of 10 to 15 years. In view of all the pain points, the pharmaceutical industry has endeavored to answer the question of how to apply new technologies and methods such as computers to the field of drug research and development.

ⅰ. Development Trends and Regional Competitiveness

1. Global AI Drug R&D Maintains Growth; North America Is the Largest Market, and Asia Ranks Third

AI can rapidly screen and analyze millions of compounds, and AI is increasingly involved in the research and development of new drugs. In 2022, the market of global AI-based pharmaceuticals attained an estimated valuation of USD 1.04 billion. In terms of the market share of global AI drug research and development, North America accounted for the largest share and Asia Pacific ranked third. The market size of global AI drug research and

development will reach USD 3.88 billion by 2025. Currently, there are approximately 700 AI drug research and development enterprises globally, of which more than 50% are concentrated in the US, while the UK and the EU account for 12.5% and 13.4%, respectively. Asia accounts for approximately 12.8%, including China with 4.7%.

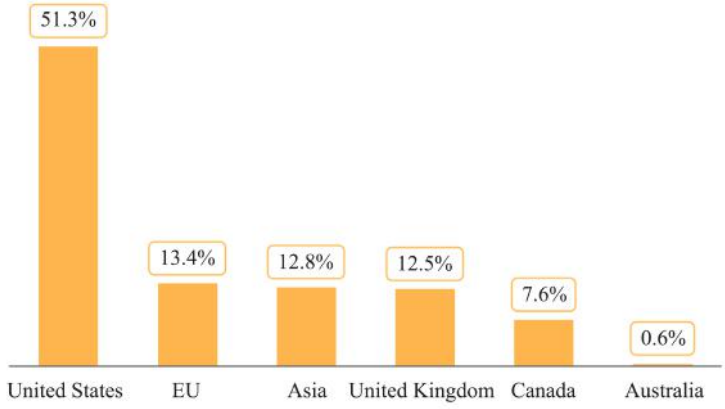

Figure 32 Percentage of Global AI Drug R&D Enterprises

(Source: www.hsmap.com)

2. The Overall Financing Capacity of Global AI Drug R&D Has Improved, with Significant Growth in Asian Investors

The total number of AI drug research and development-related financing events worldwide in 2022 reached 144, with a total amount of USD 6,202 million. Compared to the 77 financing events totaling USD 4.56 billion in 2021, both the volume and amount of financing have seen an increase. Specifically, 71 AI drug research and development financing events were in the US, 43 in China, and 30 in other countries and regions. The investment and financing activities were mainly in China, the US and Europe.

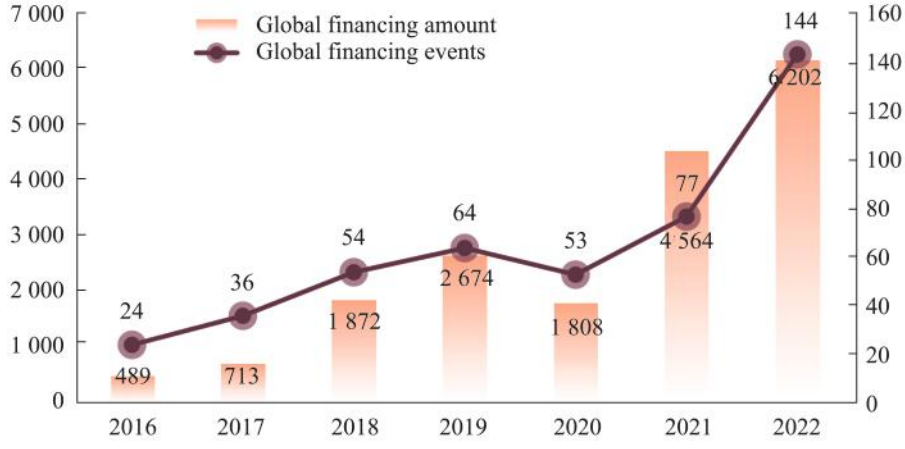

Figure 33 Financing Overview of AI Pharmaceuticals (Unit: USD Million)

(Source: Intellectual Medicine Bureau)

In terms of the number of investment institutions, approximately 1, 120 institutions and funds are currently focusing on AI-aided drug research and development, which has almost doubled in the past two years. The US continues its lead position as home to more than half of the world's AI drug research companies. Compared to 2021, the number of investors in the UK, Europe and China has surged to 212, 67 and 62, respectively. Furthermore, regarding the top 50 investors in the field of AI drug research and development, the number of investors in Asia grew significantly, primarily in China Mainland, Hong Kong SAR and Singapore.

3. The Number of Patent Applications in the Field of AI Pharmaceuticals Has Risen Significantly in the Past Decade, Especially in the Asia-Pacific Region

The above figure shows the development trends of the AI-based pharmaceutical industry worldwide by examining patent data. During the past two decades, technological innovation in the AI-based pharmaceutical industry has advanced rapidly. In 2014, there were just approximately 500 patent applications, but by 2022 this number had surged to over 5, 000 for more than a tenfold increase. Evidently, the overall trend of patent applications in the global AI-based pharmaceutical industry is one of rapid growth. In the future, AI-based pharmaceuticals will play an important role in assisting drug discovery, drug management, and many other processes of drug research and development. The expectation is that the number of patent applications in this sector will continue to expand.

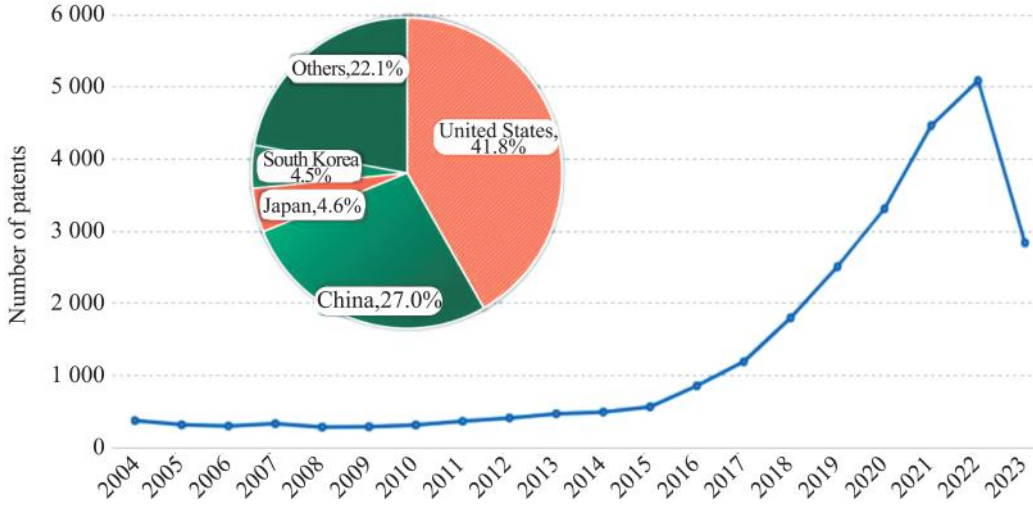

Figure 34 Trends in Global Patent Applications and Technology Contributors in AI Pharmaceuticals (Item)

(Source: PatSnap)

In terms of the distribution of technology contributors in the global AI-based pharmaceutical industry, the US has the largest number of patent applications, accounting for approximately 42%, far exceeding other countries and is the largest technology contributor.

China ranks second at 27%, and Japan and South Korea rank third and fourth at 4.6% and 4.5%, respectively. Those three Asian countries exhibit strong technological competitiveness and innovative ability in the global AI-based pharmaceutical industry, with China leading the way.

ii. Impact of Disruptive Technological Innovation

1. AI Technology Has Great Potential in Many Processes of Drug R&D

AI-based pharmaceutical research and development mainly included two phases—drug discovery and drug development in the preclinical stage—with a focus on small-molecule drugs. Drug discovery consists of three steps, namely confirmation of disease-related therapeutic targets, discovery of seedling compounds and optimization of lead compounds, acquisition of a drug candidate, and drug development. Drug development is the process of preclinical evaluation and clinical trial evaluation of candidate drugs, which requires systematic evaluation of the pharmacokinetics, pharmacology, toxicology, safety and efficacy of candidate drugs. The applications of AI in drug research and development also include the prediction of physicochemical properties (e.g., crystal-structure prediction), drug redirection and formulation development. AI can be applied not only to small-molecule drug R&D but also to the development of antibody drugs, nucleic-acid drugs and immunotherapy drugs①.

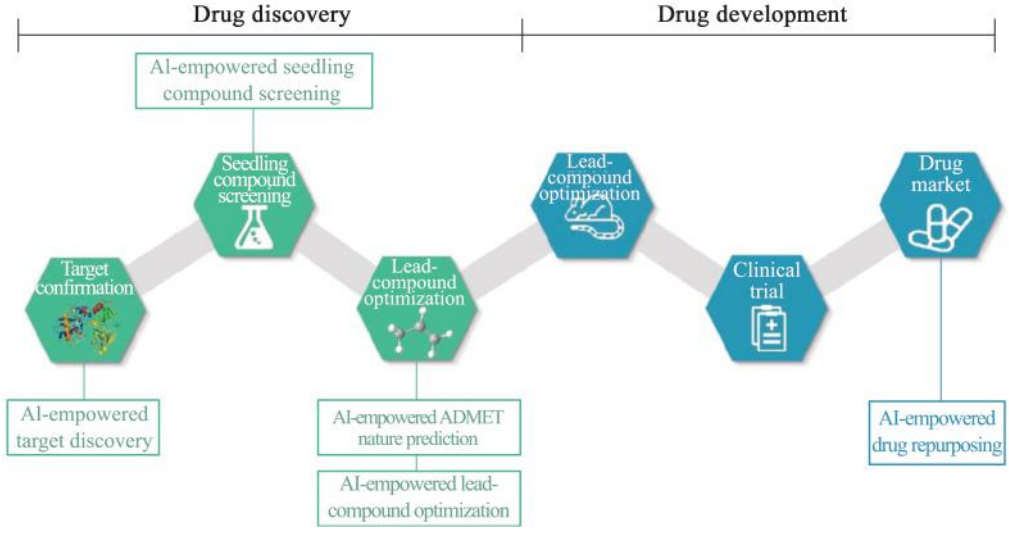

Figure 35 The Overall Process of AI-aided Drug R&D

① AI-enabled Drug R&D: AI Empowers All Processes of Drug R&D, China Science Publishing & Media Ltd. 2022, 74 (05).

（1）Target Discovery

Based on the data on genomics, proteomics, metabolomics, etc. extracted from the mass biomedical information, the differences between non-disease and disease states are analyzed through means of AI to discover targets that will have an impact on disease. The objective of drug target discovery is to obtain a causal relationship between the target and the disease from a massive database. For example, virtual screening based on protein structure can quickly identify small-molecule compounds that could interact with antiviral targets from the compound database, which can be used to discover potential drugs within a relatively brief span of time.

（2）Seedling Compound Screening

The emergence of deep generative models in the era of AI has more effectively promoted the generation of drug molecules. Generative models can learn the properties of a specific training sample and automatically generate entities with similar characteristics so that they can be applied to molecular design and seedling compound screening.

（3）Lead-compound Optimization

The general goal of AI deep generative models in the field of lead-compound optimization is to learn the distribution of chemical space and perform targeted optimization of desired chemical properties. AI tools such as the recurrent neural network, long short-term memory, variational auto-encoder, generative adversarial network and adversarial auto-encoder have all worked well in lead-compound optimization.

（4）Drug Repurposing

Previously, the repurposing of most drugs was incidental. For example, sildenafil, which was already used to treat angina, was later found to benefit erectile dysfunction as well. While drug repurposing is a valuable approach to drug development, identifying drugs through experimentation remains challenging. A number of data-driven computing methods have now been developed to speed up the repositioning of candidate drugs. Drug repurposing significantly limits time consumption and decreases the cost of research and development as compared to traditional *ab initio* drug discovery.

2. The Universal Molecular Fingerprinting Technology Has Accelerated the Screening of Drug Molecules

The variational graph encoder（VGC）contains convolutional neural network models of variational auto-encoder elements, which are trained to predict simple descriptors and binary molecular fingerprints of molecules as opposed to reconstructing and entering, allowing simultaneous prediction of various properties of small-molecule drugs, including absorption, distribution, metabolism, excretion and toxicity as well as target-specific docking-score prediction and drug interactions. This model makes possible the most advanced virtual screening available today, with an acceleration advantage of up to two orders of magnitude.

Moreover, the minimization of the latent space of VGC can be combined with Pareto optimality to accelerate the development of specific drugs, with the additional advantage of interpretability. With the intermediate mathematical representation of the variational graph encoder (latent space), agent models can be trained to predict properties of greater complexity. Previous efforts using latent space include sampling in the variational auto-encoder to generate efficacious as well as selective RIPK1 inhibitors and BRAF inhibitors. ①

3. AI Drug Development Has Limitations

AI has certain limitations despite its potential in drug research and development.

(1) The Foundation of AI-based Pharmaceuticals Must Be Reinforced

The premise of applying AI for drug discovery and development is the use of algorithms to search mass data, including compound structures, animal studies and patient information, to determine the target of the drug in vivo, which molecules are most appropriate and how to create new molecules. However, for small private companies, which may not be able to afford business libraries or own unique molecule libraries such as large pharma, the lack of data is a significant obstacle to their development. In addition to the limitations of the environment and the industry, there are also limitations in the mathematical capability of AI-based pharmaceuticals. Because the current tools such as ChatGPT require considerable mathematical capability, it's difficult to have a competent hardware base in the short term to meet the high-precision requirements of the pharmaceutical field.

(2) AI-based Pharmaceuticals Cannot Obviate the Need for Manpower in the Short Term

The experience-based and large-model forms of training require large amounts of data, and the core of AI-based pharma companies lies in data productivity. Accordingly, AI-based pharmaceuticals are mainly applied to drug discovery, lead compound screening and other early stages, and the clinical trial is still more dependent on manpower.

(3) The Acquisition of AI-based Pharma Is Costly

Currently, most AI companies cite public data to build their models, such as published literature, publicly available target libraries, and public data from drug companies and research institutes. The data varies widely in terms of specifics and quality, given that extracted data tends to be positive and failures are generally excluded. Therefore, experimentation is necessary for the accrual of high-quality data that are targeted but objective. Subsequent to data mining and refinement, the trained AI model may be more accurate, but it will lead to a linear increase in the cost of data acquisition.

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① Hilbert Yuen In, L., Robbe, P. & Hao, H., Application of variational graph encoders as an effective generalist algorithm in computer-aided drug design. Nature Machine Intelligence, 2023, 5: 754-764.

Ⅱ. Organoids

Organoids are artificial organs that are assembled from biomaterials, cells and engineered structures using multidisciplinary knowledge and technology. Specifically, it's a tissue analog having a certain spatial structure formed through the proliferation, differentiation and self-organization of stem cells (adult, pluripotent stem cells) within a matrix material under the action of chemical small-molecule inhibitors/activators, cytokines, medium additives and other substances.

Although organoids aren't human organs in the true sense, they bear similarities to native tissues in regard to cell type, structure and function. Moreover, they can mimic the structure and function of in vivo tissues to the greatest extent, allowing for long-term stable cell culture. With their capacity for self-renewal, organoids maintain the physiological structure and functional characteristics of the source tissues, and are known as "micro-organs in a petri dish". Organoids therefore have extensive applicability in the fields of organ development, precision medicine, regenerative medicine, drug screening, gene editing and disease modeling.

ⅰ. Development Trends and Regional Competitiveness

1. Organoid Research Has Developed Quickly, and the Asia-Pacific Region Has Great R&D Capacity

Since the establishment of the first organoid in 2009, the field of organoids has grown dramatically, garnering recognition from the research and industrial sectors. In 2013, Science listed organoids among the year's top 10 scientific breakthroughs. In 2013, organoids were awarded as one of the top 10 technologies of the year by *Science*. In 2015, MIT Technology Review listed organoid technology as one of the top 10 breakthroughs in the world. In early 2018, organoids were named awarded as the Best Method for 2017 by Nature Method, and in 2019 the New England Journal of Medicine called it an excellent preclinical disease model. Various visceral organoids have been constructed, such as those of the small intestine, stomach, colon, lung, bladder, brain, liver, pancreas, kidney, ovary, esophagus and heart. The range encompasses not only the normal tissue organoids but also the corresponding tumor-tissue variants.

In recent years, when searching for "organoids" in the Web of Science platform, the number of documents involving organoid technology has been increasing exponentially, including many top journals such as CNS. The above figure shows that from Hans Clevers' successful construction of organoids in the small intestine, the number of articles published in 2009 was 23, which increased to 1, 682 in 2022. Thus, 7, 019 articles have been published, indicating that the amount of scientific literature related to organoid technology has risen

dramatically each year.

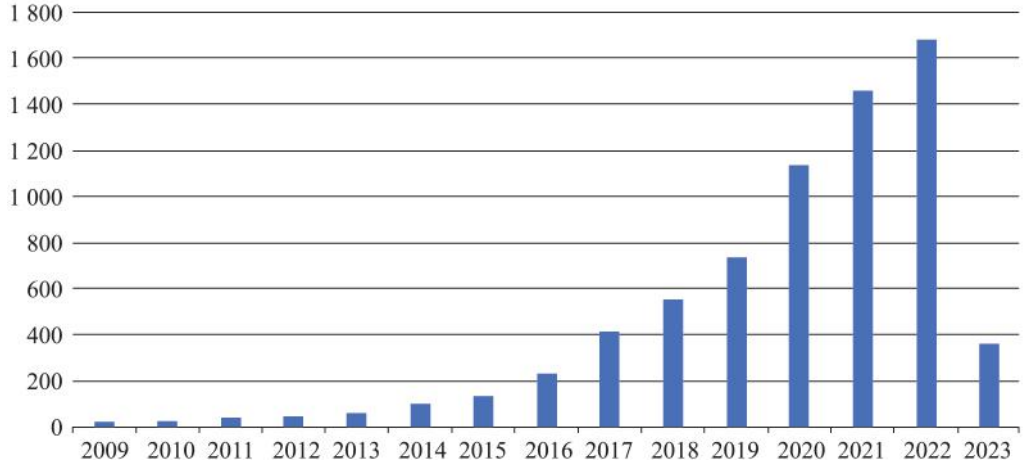

Figure 36 Volume of Global Organoid Literature by Year

(Source: Web of Science)

As of November 2022, the US has published 2, 303 papers, ranking first in the world, far ahead of other countries/regions, making it the scientific research power in the field of organoids. In Europe, Germany, the UK, the Netherlands, Italy and France have published a total of 2, 134 papers, indicating that organoid research is active throughout the continent. China, Japan, South Korea and Australia in the Asia-Pacific region all made the list, with 1, 817 papers, fewer than in North America and Europe. In terms of the average citation frequency of the literature, the Netherlands, the UK, and the US ranked in the top 10 in terms of the number of papers cited, indicating that Europe and North America lead the research of organoids.

Table 4 Global Top 10 Countries by Number of Papers in the Field of Organoids

Country	Number of papers	Number of papers Total citation frequency	Average citation frequency	H index
United States	2303	97300	42. 25	143
China	794	13628	17. 16	58
Germany	606	17439	28. 78	68
Japan	537	19334	36	63
United Kingdom	513	24648	48. 05	69
Netherlands	505	44444	88. 01	92
Italy	269	6132	22. 8	41
South Korea	259	5135	19. 83	36
France	241	5326	22. 1	33
Australia	227	7318	32. 24	41

(Source: Database of ISI Science Citation Index Expanded)

2. The Organoid Market Has Grown Dramatically, and Intestinal Organoids Account for a Large Proportion

The organoid market has experienced significant growth in recent years, both in terms of research publications and patent applications. Between 2010 and 2022, new entrants accounted for 64% of the total market. The organoid development market was valued at approximately USD 1, 031, 384, 000 in the fourth quarter of 2022. The growth of the organoid market from 2010 to 2022 was mainly attributed to the increase in investment in organoid development, the enhancement of research and development, and the increase in healthcare and drug discovery expenditures. According to research data from CSDN, the global organoid market may achieve a total revenue of USD 97 million in 2023, of which the revenue share of the intestinal organoid market will be 35. 49%. ①

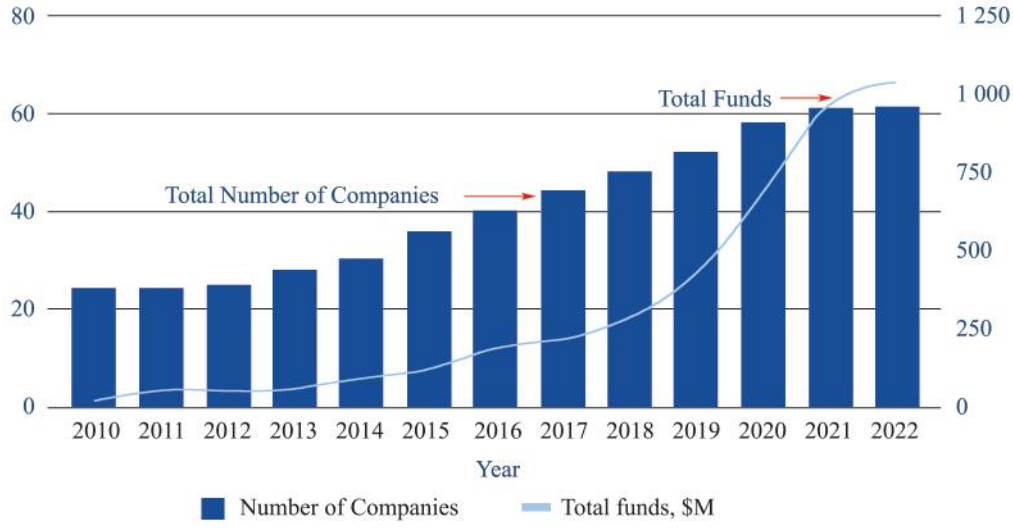

Figure 37 Number of Organoid Enterprises and Market Share Between 2010 and 2022

(Source: Yeasen Biotechnology)

3. The Number of Patent Applications in the Field of Organoid Has Grown Rapidly, and the Technology Originated in Asia

The following figure shows the development trends of the global organoid field by examining patent data. During the past two decades, technological innovation in the organoid industry has advanced rapidly. In 2004, there were just 238 patent applications, but by 2021 this number had surged to 1, 582 for more than a sixfold increase. Thus, the global organoid sector is experiencing a remarkable uptrend in patent applications.

① Global organoid market development forecast, https://www. globalmarketmonitor. com. cn/market_ news/2909215. html.

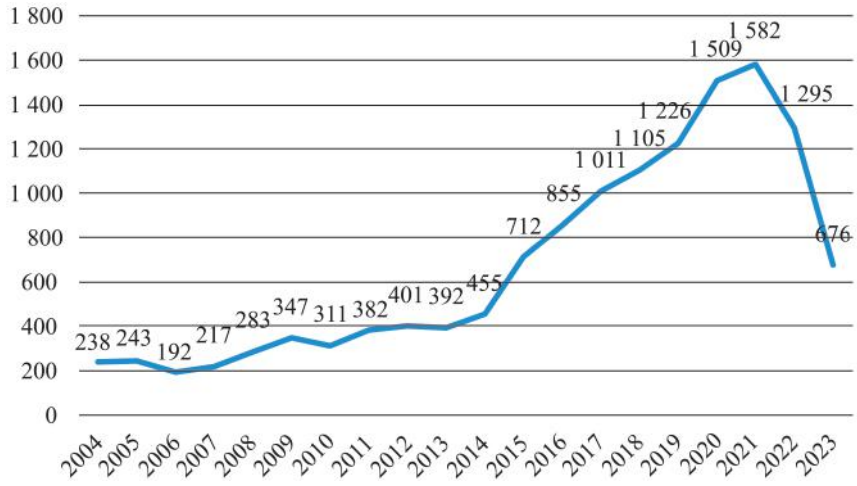

Figure 38 Trends in Global Patent Applications for the Organoid Industry (Item)

(Source: PatSnap)

Organoids are used in many aspects of research, including functional tissue induction, disease-model establishment, drug screening, anti-inflammatory tests and clinical studies. As a result, they are increasingly valued by countries around the world. The expectation is that the number of patent applications in the sector will continue its expansion.

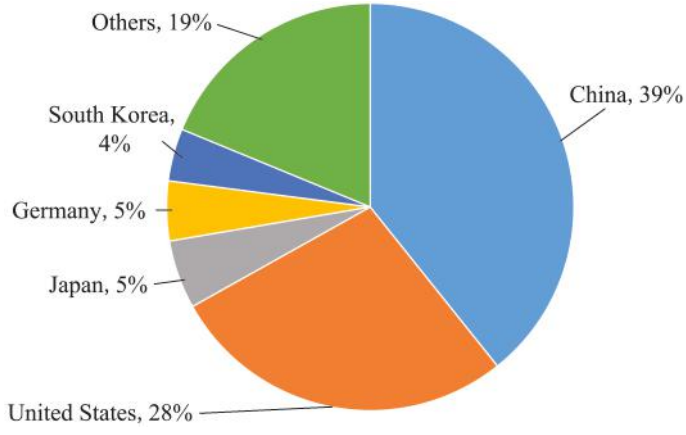

Figure 39 Geographical Distribution of Major Technology Contributors in the Global Organoid Industry

(Source: PatSnap)

In terms of the distribution of technology contributors by patent in the global organoid industry, as shown in the figure below, China has the largest number of patent applications. With a share of approximately 39%, it surpasses other countries and is the largest organoid technology contributor in the world; the US ranks second, and its patent applications in the field of solar cells account for 28%. Japan and Germany share third place with 5% each,

and South Korea ranks fourth at 4%. Consequently, Asian countries, notably China, Japan and South Korea, exhibit strong technological competitiveness and innovative ability in the global organoid field, with China leading the way.

ii. Impact of Disruptive Technological Innovation

Currently, the most cutting-edge technology is the "organoid-on-a-chip" technology, which is a combination of organ-on-a-chip technology and organoid, in which the organ-on-a-chip (OOC) is a microfluidic component as the core augmented by materials such as transparent plastics, glass or flexible polymers (e. g. , polydimethylsiloxane, abbreviated as PDMS). It has multiple cell-culture compartments that simulate the human biological environment, and they're connected by a biomimetic circulatory system. The organoid-on-a-chip approach integrates OOC and organoid technologies to develop a multi-organ physiological microsystem so that the two complement each other's strengths. Not only can it simulate the developmental process, physiological state and function of the organ, but it can also give play to the advantages of the organ chip in the construction of complex models. However, the organoid-on-a-chip technology is still in the early-research phase. In addition to integrating the advantages of organoids and OOC, the challenges of both also exist. ①

1. The Organoid-on-a-chip Technology Is Still in Its Infancy

The organoid-on-a-chip concept was first introduced in a review published in Science in 2019. The organoid-on-a-chip is also regarded as one of the most cutting-edge directions in the development of OOC. In other words, the organoid-on-a-chip is an "upgraded" OOC or an extension of the OOC concept.

As a "disruptive technology that could change the future", organoid-on-a-chip research is on the rise. Generally, the basic research in the field of organoid-on-a-chip has been developed for almost 20 years, and there has been long-term research and technology accumulation with respect to model simulation.

The US NIH, FDA and Department of Defense, in 2011, led the launch of the Microphysiological Systems (MPS), thus elevating the development and application of organoid-on-a-chip technology to the national strategic level. Their belief was that the "highly biomimetic humanized chip model" would significantly reduce the cost and time of new drug discovery and bring about a significant revolution in the field of new drug development. Concurrently, European countries expressed optimism in regard to the development of organoid-on-a-chip technology in drug research and development as well as precision medicine. They've continued to invest in supporting its development. In 2021, China began to systematically promote the development of organoid-on-a-chip technology at

① Organoid and OCC Industry White Paper, p. 9.

the scientific and regulatory levels.

Generally, however, the organoid-on-a-chip technology is still in the basic research phase, so it hasn't been used extensively in drug research and development. The reason is that the organoid-on-a-chip is divided into chip technology and modeling, covering multidisciplinary knowledge in the areas of pharmacology, biomedical engineering, biology, medicine, materials science, fluid dynamics and others. It's an industry with high technical barriers and multidisciplinary knowledge, and its development process covers chip design, process development and production, modeling, functional evaluation and drug testing.

Organoid-on-a-chip research is mainly concentrated in university laboratories. However, the products of laboratory research are usually used to address a particular local problem, lacking systematic university, as a result of which mass production and use are less than optimal. Moreover, given the gap between university R&D and the demand in the marketplace, the commercialization of the technology needs to be driven by more start-ups and large pharma.

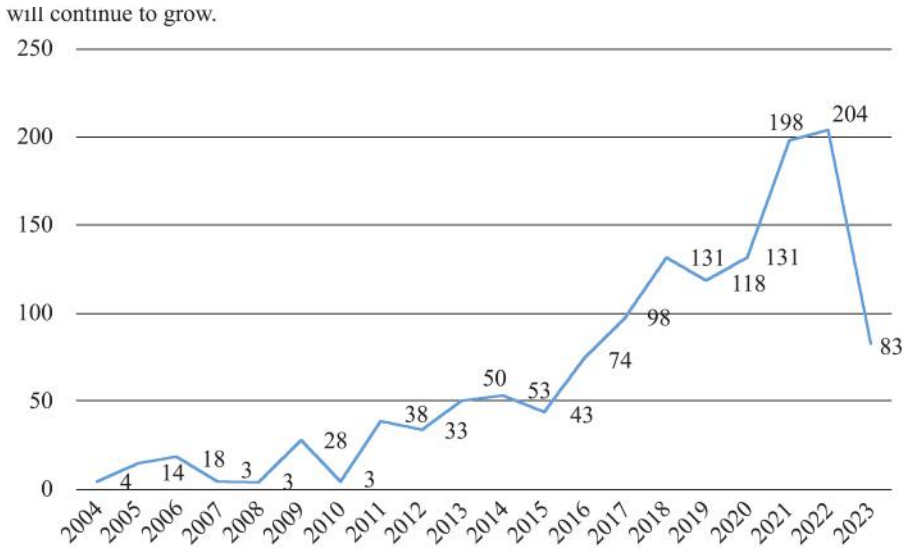

Figure 40 Trends in Global Organoid-on-a-chip Patent Applications (Item)

(Source: PatSnap)

Based on the analysis results of patent application trends of global organoid-on-a-chip, in the past two decades, the number of global patent applications of organoid-on-a-chip has shown exponential growth. In 2004, there were just four patent applications, but by 2021 this number had surged to 204, amounting to an increase of 50 times. Innovation in this field is heavily influenced by the policies and measures that have been introduced by various countries. Various countries have, in recent years, promoted organoid-on-a-chip research by

unveiling a series of favorable policies. Those measures have made innovators more enthusiastic while also fostering more research and development. Thus, the number of patent applications in this field will continue to grow.

2. Technology Development Trends

The organoid-on-a-chip features microstructures with high throughput and high sensitivity, which can integrate a series of experimental processes such as organoid sorting, cultivation, observation, stimulus induction, detection and analysis. Consequently, it can be applied to developmental or disease models, drug research and development, immune response therapy, microbial infections, and other biological fields, enhancing the predictions of clinical therapeutic solutions and thereby enhancing the efficiency of experimentation.

Despite the significant biomedical advantages of the organoid-on-a-chip technology, problems remain:

(1) PDMS, a material widely used in organoid-on-a-chip, has disadvantages such as poor stability and adsorption of hydrophobic molecules, which can lead to a decrease in the concentration of the reagents added, resulting in inaccurate experimental data.

(2) The organoid-on-a-chip tends to be miniaturized, but it will also increase the sensitivity requirements for the instruments of detection. Moreover, the organoid-on-a-chip still isn't compatible with some commonly used cell-analysis instruments, such as mass spectrometry, liquid chromatography, nuclear MRI (Magnetic Resonance Imaging), etc. The integration of the organoid-on-a-chip technology and the cell-analysis instruments may be the future trend of organoid-on-a-chip development.

(3) It is often difficult to collect and carry out subsequent experiments after sorting out the desired organoid population using the organoid-on-a-chip technology. Fortunately, some researchers have designed the InSMAR chip, which can be used for drug-sensitivity testing, subsequent in-situ cryopreservation and the transfer of organoids. ①

① Progress of the application of organoid-on-a-chip in medical research, https://www.sohu.com/a/534295850_120554400.

Chapter Ⅵ
New Energy and Low-carbon Technologies

Ⅰ. Energy Storage

With the backdrop of trying to achieve peak carbon emissions and carbon neutrality, using clean energy alternatives is the only way to achieve these targets. As such, the percentage of clean energy consumption is gradually increasing, but the large-scale input of unstable power supplies tests the stability of the power grid, with the curtailing of wind and solar power in some areas resulting in the waste of resources. Energy storage has become key to the use of clean energy alternatives, complementing the development of new energy and improving the flexibility and safety of the energy system.

In a broad sense, energy storage refers to the cyclic process from storing a form of energy in the same form or converting it into another form of energy through a medium or device to releasing it in a specific energy form based on the needs of future applications.

In a narrow sense, energy storage specifically refers to the storage of electrical energy. This includes a series of technologies and measures for the storage of energy that gets generated and the release of that energy as required through chemical or physical methods.

Depending on the medium of storage and the technical route, energy storage can be divided into five main categories, namely mechanical, electrochemical, electromagnetic, thermal, and hydrogen energy storage. More specifically, known mechanical energy storage technologies include pumped energy storage, compressed air energy storage, flywheel energy storage, and gravity energy storage. Electrochemical energy storage technologies include lithium-ion batteries, lead storage batteries, sodium-ion batteries, and flow batteries, while electromagnetic energy storage technologies include supercapacitors for energy storage and superconducting magnetic energy storage.

ⅰ. Development Trends and Regional Competitiveness

1. Asia, Europe and the Americas Are the World's Leading Markets for Energy Storage, While the Asia-Pacific Region Is the World's Largest Regional Energy Storage Market

Since 2022, the global pattern for energy supply and demand has entered an adjustment phase, with more and more countries listing energy storage as a necessary method of

accelerating the clean energy transition. According to data from the China Energy Storage Alliance (CNESA), in 2022 the installed capacity of new power energy storage projects worldwide that were in operation was reportedly 30.7 GW, representing a year-on-year increase of 98%. This included 20.4 GW of installed capacity of new projects based on new energy storage technologies. China, Europe and the US continue to lead in the development of global energy storage markets, with their combined share of these markets reaching 86%.

According to CICC's latest forecast, the global demand for energy storage is expected to reach 189 GWh in 2023, representing a year-on-year increase of over 60%. Asia, Europe and the Americas have become the world's three biggest markets for energy storage. Moreover, the International Energy Agency (IEA) forecasts that in the next five years, installed energy storage capacity worldwide will expand by 56%, and is expected to reach approximately 270 GW by 2026①.

According to a forecast report by BloombergNEF, after energy storage deployments reached a new high in 2022 the global energy storage market is now growing at a 23% compound annual growth rate, with annual additions projected to reach 88 GW/278 GWh in 2030, or 5.3 times the expected 2022 level for new installations. By 2030, China will replace the US to become the biggest energy storage market in the world.

The US is by far the world's largest market for energy storage, with the Americas expected to represent 21% of annual storage capacity on a GW basis by 2030. The development of this market in the US is led by a pipeline of large-scale projects in California, the Southwest and Texas. In 2022, Europe, the Middle East and Africa (EMEA) added 4.5 GW/7.1 GWh to its annual energy storage deployments. Residential batteries are now the largest source of storage demand in the region, and they are expected to remain so until 2025. EMEA will continue to quickly expand its market size, growing to represent 24% of annual energy storage deployments on a GW basis by 2030. EMEA is expected to reach 114 GW/285 GWh cumulatively by the end of 2030, a 10-fold growth in gigawatt terms, with the UK, Germany, Italy, Greece and Türkiye leading these additions in capacity. The Asia-Pacific (APAC) region continues to maintain its lead in installed capacity on a gigawatt basis. The cumulative deployment of this capacity for APAC is expected to increase by 44% in gigawatt terms to reach 39 GW/105 GWh in 2030. Japan's federal and local governments announced annual subsidy programs for utility-scale batteries, while South Korea set a storage target of 25 GW/127 GWh by 2036②.

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① Chen, M. 2023 Full map of China's energy storage industry, https://www.163.com/dy/article/I9UIM88I055631P7.html?spss=dy_author, (2023-7-18) & cited on (2023-9-12).

② Bloomberg NEF. 1H 2023 Energy Storage Market Outlook, https://about.bnef.com/blog/1h-2023-energy-storage-market-outlook/, (2023-3-21) & cited on (2023-9-12)

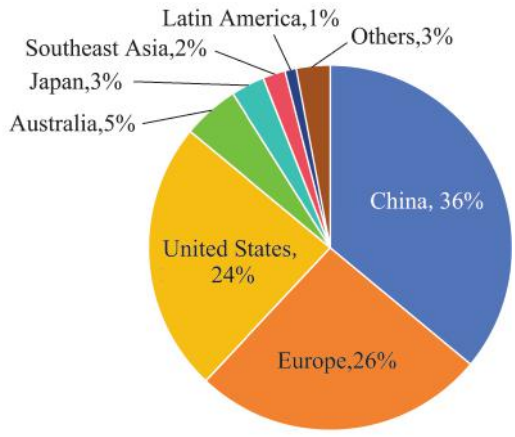

Figure 41 Global Distribution of New Energy Storage Projects in 2022 by Destination
(Source: 2023 Full Map of China's Energy Storage Industry)

2. Energy Storage Deployments in China Experienced Rapid Growth

According to data from CNESA, China's cumulative installed capacity of power storage projects in operation had reached 59.8 GW by the end of 2022, with pumped energy storage falling below 80% of this total for the first time. Meanwhile, new energy storage technologies continued developing rapidly, with installed capacity exceeding 10 GW for the first time to reach 13.1 GW, representing a year-on-year increase of 128%. While lithium-ion batteries continue to hold a dominant market share among new energy storage technologies, significant scale expansion also occurred in projects based on other technological routes such as compressed air energy storage, flywheel energy storage, flow batteries and sodium-ion batteries, with gradual increases in application modes①.

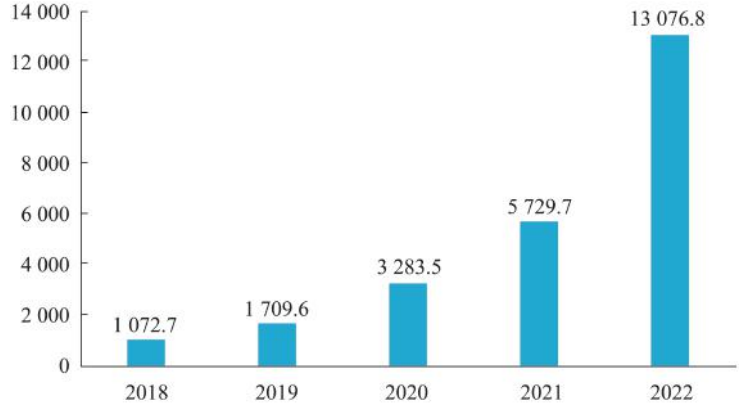

Figure 42 Cumulative New Energy Storage Deployments in China from 2018 to 2022 (MW)
(Source: 2023 Full Map of China's Energy Storage Industry)

① Chen, M. 2023 Full map of China's energy storage industry, https://www.163.com/dy/article/I9UIM88I055631P7.html?spss=dy_author, (2023-7-18) & cited on (2023-9-12).

3. The Energy Storage Industry Experienced a General Trend of Rapid Growth in the Number of Patent Applications

The following figure shows development trends in the energy storage industry worldwide by analyzing patent data. During the past two decades, technological innovation in the energy storage industry has advanced rapidly. In 2004 there were only 2,472 patent applications, but by 2022 this number had increased over tenfold, surging to 25,889. The overall trend of patent applications in the global energy storage industry is evidently one of rapid growth. Currently, the world is paying an increasing amount of attention to energy storage technologies. The expectation is that the number of patent applications in this sector will continue to increase in the future.

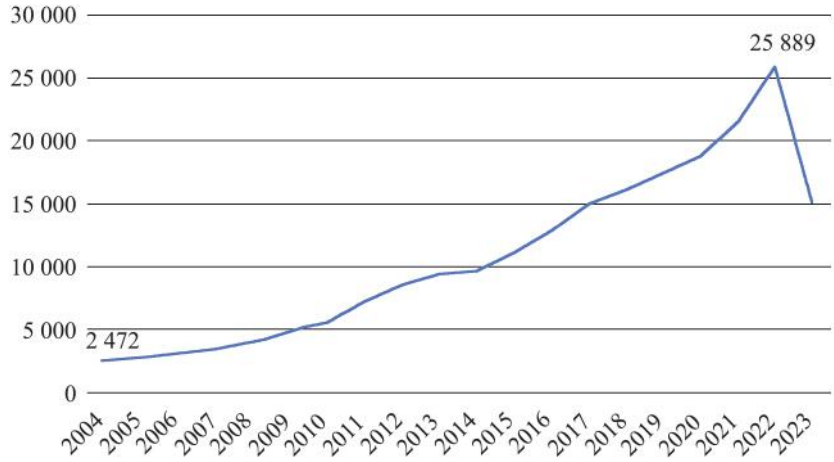

Figure 43 Global Trends in Patent Applications Related to the Energy Storage Industry (Item)

(Source: PatSnap)

ii. Impact of Disruptive Technological Innovation

According to the forecast data from CNESA, since new energy storage deployments have enjoyed significant growth during the period of China's 14th Five-Year Plan and since the goal of achieving carbon neutrality is a huge positive factor for the renewable energy and the energy storage industries, and fully taking into consideration the support of all relevant direct or indirect policies, the forecast is that new energy storage deployments in China will reach 147 GW (conservatively) or 256 GW (ideally) by 2030.

Although other energy storage technologies such as compressed air energy storage and molten salt energy storage also have tremendous potential for future development, comprehensively speaking, pumped energy storage and electrochemical energy storage will continue to play dominant roles in the energy storage market. It is forecast that energy storage deployments in China will reach 267 GW (conservatively) or 376 GW (ideally) by

2030①.

1. Pumped Energy Storage

（1）Pumped Energy Storage Is the Most Well-developed and Widely Applied Energy Storage Technology.

Pumped energy storage technology uses excess electricity from the grid to drive pumps when demand on the grid is low, pumping water from the lower reservoir to the upper reservoir for energy storage. Water is then discharged to the lower reservoir for power generation when demand on the grid is high.

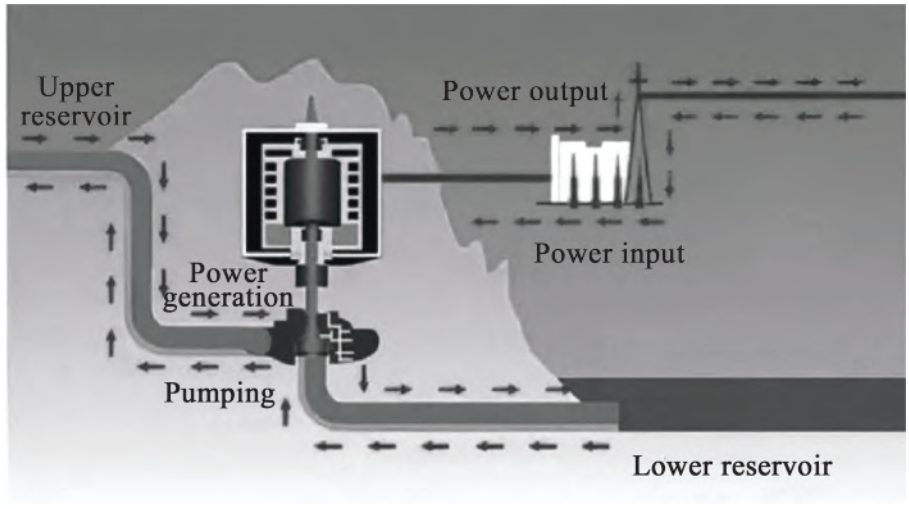

Figure 44 Technical Principles of Pumped Energy Storage

（Source: Applications and Development Trends of Energy Storage）

Pumped energy storage is the main form of energy storage that China has adopted. Its advantages include mature technology, high power output, large storage capacity, high efficiency and the greatest number of applications. According to the 2021 *Report on the Development of the Pumped Energy Storage Industry* that was released by the China Renewable Energy Engineering Institute（GREEI）, the average total static investment in approved pumped energy storage power stations for 2021 was RMB 5,367/kW. As the scale increases, one would normally expect this to result in a significant reduction in the unit cost. Since the cost of pumped energy storage is between RMB 0.21 and 0.25 per kWh, the technology has proven to be economically efficient. The technology does have a disadvantage in that its applications require substantial land and water resources, and another shortcoming comes from the difficult and time-consuming nature of constructing facilities. Pumped energy storage can be used for large-scale, centralized energy storage and in the construction of new

① Qianzhan Industrial Research Institute. Forecasting 2023: 2023 *Panoramic Map of China's Energy Storage Industry*（including the current market status, competition status, development trends, and more）.

power systems, it can also be used as an important means of flexible power regulation. This facilitates energy management and peak regulation for the power grid.

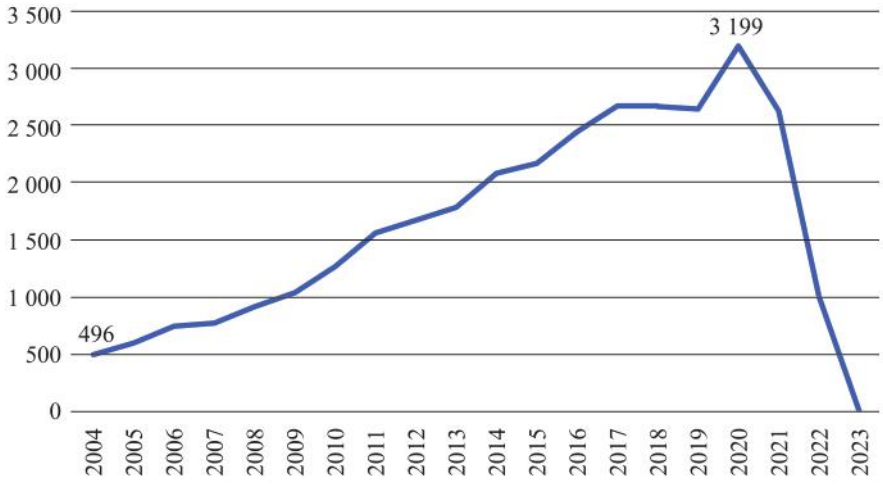

Figure 45 Global Trends in Patent Applications Related to Pumped Energy Storage (Item)

(Source: PatSnap)

In the study of development trends in pumped energy storage, it has been discovered through patent data that pumped energy storage technology has maintained continuous development and steady growth since 2004, with its most rapid development taking place during the past two decades. Since 2004, the number of relevant patent applications has grown significantly from 496 in 2004 to 3,199 in 2020, a more than six-fold increase. Currently, research on technologies related to pumped energy storage remains relatively active.

(2) Technology Development Trends

Based on China's *Medium and Long-term Development Plan for Pumped Energy Storage* (2021-2035), major tasks concerning the future development of the technology include: Major technological research programs focused on intelligent and machinery-based construction of large underground cavity groups and on reservoir dam construction and seepage control in complex terrain and geological conditions; innovation regarding the development patterns of pumped energy storage, including the construction of hybrid pumped energy storage power stations based on cascade reservoir power stations in China's mid-eastern region, and the exploration of the use of cavities (such as abandoned mines or quarries) as underground reservoirs by integrating methods such as the construction of pumped energy storage power stations for mine pit governance; the construction of medium or small pumped energy storage power stations as appropriate in provinces, autonomous

regions, or municipalities directly administered by the central government that have plentiful relevant resources; major technological research programs on the independent design and manufacturing of ultra-high head, large-capacity engine clusters for energy storage and large-capacity variator clusters with simultaneous improvement in the domestically manufactured level of auxiliary devices such as excitation systems, governors and frequency converters; the facilitation of digital and intelligent pumped energy storage using technologies such as the Internet of things, cloud computing and big data; and the development of an intelligent comprehensive monitoring platform for pumped energy storage power stations in China with functions like real-time monitoring, inspection tours and supervision management①.

2. Electrochemical Energy Storage

Electrochemical energy storage is a technology that achieves the storage and output of electrical energy through the conversion between electrical energy and chemical energy. It has the technical characteristics of rapid response and two-way adjustment along with the advantages of strong environmental adaptability, small decentralized configuration and a short construction period, and it plays diverse roles in the power supply, the power grid and on the user side. There are various electrochemical energy storage technology routes at different development stages. In terms of the analysis below, four electrochemical energy storage technologies have been selected that have reached the commercialization or demonstration stage, namely lithium-ion batteries, sodium-ion batteries, vanadium redox flow batteries and zinc-bromine flow batteries. Lithium-ion-battery-based energy storage has outstanding advantages in terms of technical characteristics, while vanadium retro batteries and sodium batteries are expected to be among the new stars on the energy storage industry's development track.

(1) Technologies Related to Lithium-ion Batteries Have Seen Explosive Growth

The operation of lithium-ion batteries mainly relies on the movement of lithium ions between the anode and the cathode. During the charging process, lithium ions are deintercalated from the anode and intercalated into the cathode through electrolytes, rendering the cathode lithium-rich; during the discharging process, the above reactions take place in reverse. A lithium-ion battery is composed of four components, namely the anode, the cathode, the electrolyte and the separator. More specifically, the anode material determines multiple core properties of a lithium-ion battery, such as the battery capacity and the battery life, and its cost accounts for approximately 40% of the total cost of a lithium-ion battery.

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① Wei, M. & Xiang, D. Applications and development trends of energy storage, Industrial Safety and Environmental Protection, 49 (S1): 4-12 (2023).

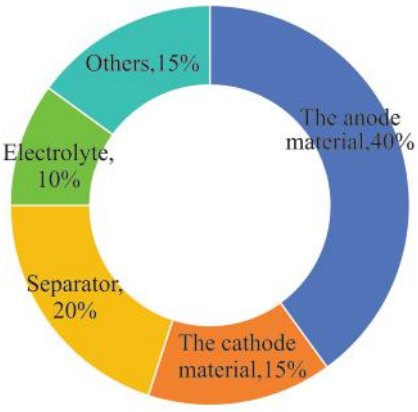

Figure 46　Cost Structure of a Lithium-ion Battery by Component

（Source：Applications and Development Trends of Energy Storage）

Since today's lithium-ion batteries have an energy density of 200-300 W · h/kg and a fast response speed, they are suitable for energy storage systems that last for less than four hours. In terms of the anode material, types of lithium-ion batteries for energy storage that have boomed in recent years include lithium iron phosphate batteries, ternary lithium batteries, lithium-ion cobalt oxide batteries and lithium-ion manganese oxide batteries. The table below shows how they compare in terms of major technical indicators. In terms of cost of investment, cycle life and safety, lithium iron phosphate batteries have the best overall performance. With advantages such as high stability and long cycle life, they are now a popular technology for electrical energy storage in China. According to the *Specifications for the Lithium-ion Battery Industry* (*Version* 2021) issued by the Ministry of Industry and Information Technology, the energy density of a lithium-ion battery cell must be ⩾ 145 W · h/kg, the energy density of a lithium-ion battery pack must be ⩾ 100 W · h/kg, and the cycle life of a lithium-ion battery must be ⩾ 5,000 times. Thanks to the development of the electric automobile industry, the cost of lithium-iron phosphate batteries has dropped rapidly and is now just RMB 0.7-1.0 per kWh. Currently, thanks to a series of improvements such as lithium supplementation, silicon doping and the application of hybrid solid-liquid electrolyte systems, lithium-iron phosphate batteries now have an energy density of over 200 Wh/kg, with the volume efficiency of battery cells in battery packs rising from 40% to 60%. In terms of the disadvantages, mining lithium resources is difficult in China and incurs considerable costs, and also lithium-ion batteries cause environmental pollution unless there are effective recycling measures in place. Additionally, the total energy stored by a lithium-ion battery is inversely proportional to its safety, which means that the greater the total amount of energy, the worse the performance becomes in terms of heat dispersion, making it imperative to solve the safety problems associated with lithium-ion batteries.

Table 5 Comparison of Different Anode Materials for Lithium-ion Batteries by Major Technical Indicators

Item	Number of Cycles/Times	Low-Temperature Performance	High-Temperature Performance	Safety
Lithium-ion cobalt oxide materials	500-1, 000	Excellent	Excellent	Poor
Lithium-ion manganese oxide materials	500-1, 000	Excellent	Poor	Good
Lithium iron phosphate materials	⩾ 2, 500	Average	Excellent	Excellent
Ternary lithium materials (lithium nickel-manganese-cobalt oxide)	1, 500-2, 000	Excellent	Average	Good

(Source: Applications and Development Trends of Energy Storage)

Judging by the current application status, lithium iron phosphate batteries, with their long cycle lives and high levels of safety, will play a major role in the future energy storage market. Thanks to cost decreases and improvements in overall performance for lithium iron phosphates, lithium-ion battery technologies for energy storage are becoming widely used in all processes of the power system, from power generation, power transmission and power distribution to power consumption. Currently, the market for lithium-ion batteries is considerably commercialized and has seen explosive growth. According to the *Outlook for the Development Strategy of China for Lithium-ion Batteries for Energy Storage* that was co-released by the China Center for Information Industry Development and China Southern Power Grid Electric Vehicle Service Co., Ltd., the forecast is that lithium-ion-battery-based energy storage deployments in China will reach 50 GW by 2025 with a market space of approximately RMB 200 billion, and will reach 600 GW by 2035 with a market space of approximately RMB 2 trillion.

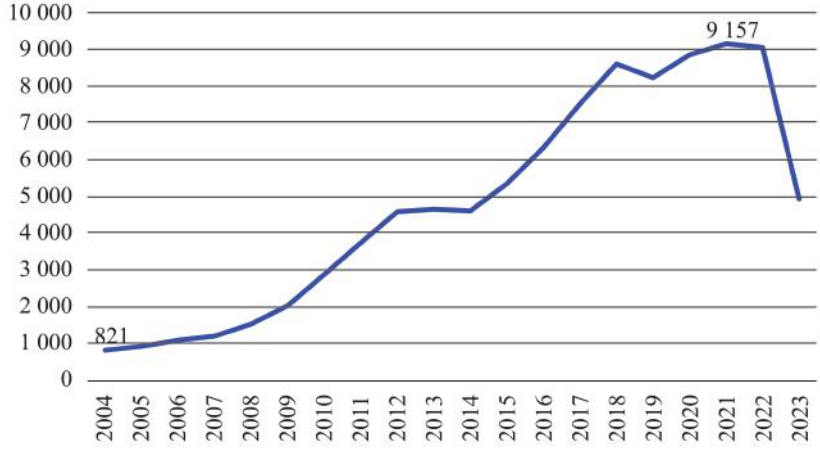

Figure 47 Global Trends in Patent Applications Related to Lithium-ion Batteries (Item)

(Source: PatSnap)

The following figure shows development trends in the field of lithium-ion batteries by analyzing patent data. During the past two decades, the number of patent applications related

to solar batteries has maintained growth with some fluctuations. The annual number of these patents has exceeded 5,000 in almost every year between 2014 and 2021. The global development of lithium-ion battery technologies is currently experiencing growth. As lithium-ion battery capacity increases worldwide, so does the scale of the industry. Manufacturers and innovators are therefore expected to increase R&D investments in this field, which will in turn drive continued growth in the number of patent applications.

(2) Technology Development Trends

The direction of innovation in lithium-ion battery technologies is primarily geared toward seeking technological breakthroughs on a 100-MW basis that achieve higher security, lower costs and longer cycle life. These breakthroughs mainly include the following: In terms of technologies for the mining and recycling of lithium resources, processing procedures must be simplified and isolation materials must have higher adsorption performance; in terms of anode materials, although lithium supplementation and other temporary measures can currently be taken to facilitate technological development, development trends for lithium-iron phosphate anode materials are likely to experience gradual improvement; in terms of cathode materials, future development trends are basically concentrated on silicon-carbon composites with high specific capacities; in terms of separators, innovation trends are primarily concentrated on the manufacturing processes and technological development for the purpose of increasing heat stability and effectively improving safety performance; and in terms of electrolytes, more must be done to improve the safety and stability of batteries. Additionally, according to the *14th Five-Year Implementation Plan for the Development of New Energy Storage Technologies* issued by China's National Development and Reform Commission and National Energy Administration, development trends in lithium-ion battery technologies also include several major technological research programs (such as programs on intelligent sensing technology, isolation technology for thermal runaway, safety control technology and smart regulation technology) and the enhancement of R&D for key technologies and equipment (such as research on key technologies, equipment and the design of integrated optimization related to new lithium-ion batteries and R&D on reserves, solid-state lithium-ion batteries and other next-generation high-energy-density energy storage technologies).①

Ⅱ. Nuclear Power Generation

Nuclear energy, also known as atomic energy, is a form of energy released from the nucleus of an atom when its structure changes. Generally, nuclear energy is released from the nucleus of an atom through one of the following three nuclear reactions: (1) Nuclear fission, where larger atomic nuclei split to release their binding energy; (2) nuclear fusion, where smaller atomic nuclei join into each other to release their binding energy; and (3)

① Wei, M. & Xiang, D. Applications and development trends of energy storage, Industrial Safety and Environmental Protection, 49 (S1): 4-12 (2023).

radioactive decay, where energy is released due to the spontaneous decay of atomic nuclei. Energy released from nuclear fission is mainly used to generate electricity in nuclear power plants. Currently, nuclear electricity, hydroelectricity and thermal electricity constitute the world's three main energy pillars.

ⅰ. Development Trends and Regional Competitiveness

1. Nuclear Energy Is Playing an Increasingly Prominent Role in the Global Transition to Sustainable Energy, with the Asia-Pacific Region Maintaining Strong Growth in its Development of Nuclear Electric Power Generation.

Nuclear energy is a clean, low-carbon, efficient and stable form of energy that plays an important role in safeguarding energy security, promoting the transition to sustainable energy, and facilitating the realization of climate-related goals like peak carbon emissions and carbon neutrality. Currently, an increased amount of attention is being paid to energy diversity and independent and controllable energy supplies worldwide. For many countries, developing nuclear energy is a realistic option for ensuring energy security.

A study led by the International Energy Agency (IEA) indicates① that in order to reach the goals set in the *Paris Agreement* regarding climate change, global nuclear power capacity must double by 2050. According to data from the Power Reactor Information System (PRIS) of the International Atomic Energy Agency (IAEA) that was updated on April 19, 2023, there were 420 nuclear power reactors in operation and 56 nuclear power reactors under construction worldwide, representing a total net installed capacity of 374, 827 MWe and 58, 595 MWe respectively②.

Table 6 Nuclear Power Reactor Deployments in Various Countries (by March 2023)

Country	China③	United States	Russia	France	Japan
Reactors in operation or with operation suspended	55	92	37	56	33
Installed capacity of existing reactors (MWe)	53, 181	94, 718	27, 727	61, 370	31, 679
Reactors under construction	22	2	3	1	2
Installed capacity of reactors under construction (MWe)	24, 781	2, 500	2, 810	1, 650	2, 756
Planned reactors to be built	46	3	25	0	1
Installed capacity of planned reactors to be built (MWe)	51, 360	2, 550	23, 525	0	1, 385

(Source: World Nuclear Association; summarized by the China Energy Media Institute of New Strategies for Energy Security)

① China Energy Media Institute of New Strategies for Energy Security. *Global Nuclear Energy Development Trends and Insights (2023)*, (2023).

② MWe stands for "megawatt electric" and is a unit of power used in the nuclear power industry.

③ Note: Data from Taiwan (China) is not included.

According to the *Annual Comprehensive Report on Nuclear Power Operation in China (2022)* released by the China Nuclear Energy Association in 2023, as of December 31, 2022, there were a total of 422 nuclear power reactors connected to the power grid worldwide, representing a total installed capacity of 399 MWe. Six nuclear power reactors were newly connected to the global power grid in 2022, most of which are located in the Asia-Pacific region. More specifically, of these six reactors, two are located in China, one in Pakistan, one in South Korea, one in the United Arab Emirates and one in Finland.

This indicates that both the number of nuclear power reactors and the number of nuclear power reactors connected to the power grid are showing a growth trend, with nuclear energy playing an increasingly prominent role in the global transition to sustainable energy.

As shown in the table below, in 2022 global nuclear energy production was slightly lower than in 2021. North America was the world's largest producer of nuclear power with 909.6 billion kWh of annual nuclear power production, followed by Europe and the Asia-Pacific, which supplied 741.5 billion kWh and 737.9 billion kWh of nuclear power respectively. Nuclear power produced by these three regions far exceeds what is produced by other regions around the world. As for production growth, in 2022 nuclear power production in the Asia-Pacific grew by 3.33%. It also grew by 0.43% in countries that are members of the Commonwealth of Independent States, but experienced negative growth in all other regions.

In 2022, although there was still a gap between nuclear power production in the Asia-Pacific and in North America, nuclear power production in the Asia-Pacific had already reached the same level as in Europe. Moreover, even as nuclear power production in North America and Europe both showed negative year-on-year growths in 2022 (with a growth rate of -16% in Europe), the Asia-Pacific region maintained strong positive growth (3.3%) in its nuclear power production.

Table 7 Global Nuclear Power Production (in'00 million kWh)

Ranking	Region	2021	2022	YoY Growth Rate in 2022
1	Asia-Pacific	7, 141	7, 379	3.33%
2	Commonwealth of Independent States	2, 302	2, 312	0.43%
3	North America	9, 246	9, 096	-1.62%
4	Central and South America	249	220	-11.65%
5	Europe	8, 823	7, 415	-15.96%
6	Africa	124	101	-18.55%
	World	28, 025	26, 790	-4.41%

(Source: Statistical Review of World Energy 2023)

The figure below shows the world's top 10 nuclear power producers in 2022. It can be seen in the figure that the world's major nuclear power producers include the US and Canada

in the North American region, the Chinese mainland, South Korea and Japan in the Asia-Pacific region, and various European countries. More specifically, the nuclear power produced by the world's top five producers (namely, the US, the Chinese mainland, France, Russia and South Korea) was far more than that produced by those ranking from sixth place to tenth place. Statistically, the US supplied 812.1 billion kWh of nuclear power and was the world's largest producer with a global contribution of 30.3%. As for the Asia-Pacific region, the Chinese mainland was the world's second-largest producer with 417.8 billion kWh of nuclear power production and a global contribution of 15.6%, South Korea was the fifth largest with 176,054 million kWh of nuclear power production and a global contribution of 6.6%, and Japan was ninth largest with 51,774 million kWh of nuclear power production and a global contribution of 1.9%.

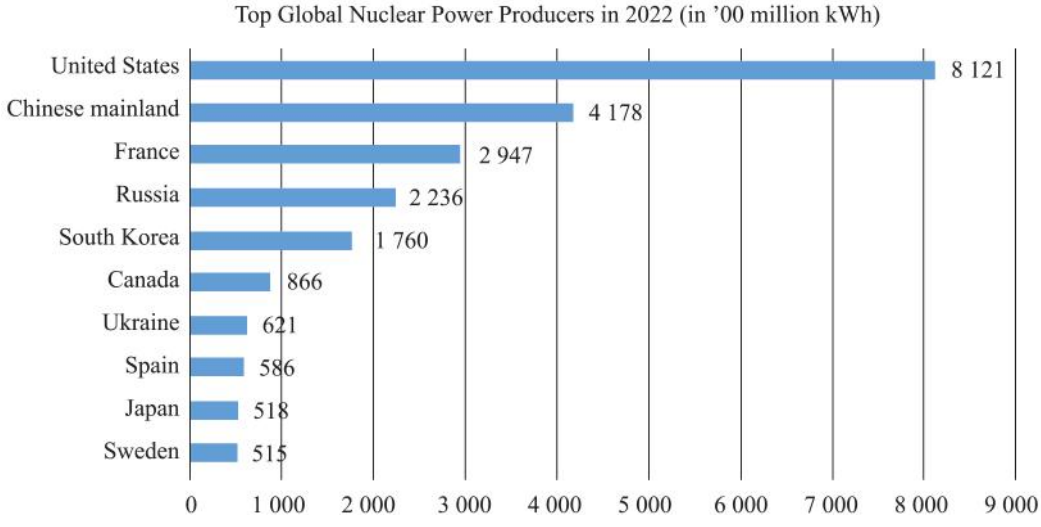

Figure 48 Top 10 Nuclear Power Producers in 2022

Source: 2023 Statistical Review of World Energy

The Chinese mainland has consistently been a leading player in the Asia-Pacific nuclear energy market in recent years, as the total global contribution of all other Asia-Pacific countries was dwarfed by that of China. From a global perspective, the Chinese mainland also held a dominant position, maintaining strong growths in terms of both the number of nuclear power reactors and the installed capacity of nuclear power reactors under construction.

2. The Nuclear Power Generation Industry Experienced a Growth Trend in Terms of Patent Applications, with Asia Becoming the World's Main Technological Source in the Field of Nuclear Energy.

Figure 49 shows development trends in the nuclear power generation industry worldwide through the analysis of patent data. During the past two decades, technological innovation in

the nuclear power generation industry has advanced rapidly and can be divided into roughly three stages: Before 2012 was the stage of rapid development; due to the Fukushima Daiichi Nuclear Accident, technological development slowed down slightly between 2012 and 2017 before accelerating again after 2017. The number of patent applications related to the nuclear power generation industry rose from 2,427 in 2004 to 14,011 in 2021, a nearly six-fold increase. Although the number of patent applications in 2022 was slightly lower than in 2021, there were still 12,104, indicating that the global nuclear power generation industry is still experiencing a period of rapid growth.

The figure below shows the distribution of technological source countries for the global nuclear power generation industry in terms of patents. It shows that China① has the largest number of patent applications, accounting for approximately 42% of the global total. This is far more than for any other country, indicating that China is the largest technological source country in the global nuclear power generation industry. Japan ranks second, with approximately 25% of the share of the global total, and the US and South Korea rank third and fourth with their shares of the global nuclear power generation industry reaching 11% and 7% respectively. Consequently, Asian countries, especially China, Japan and South Korea, exhibit strong technological competitiveness and innovative ability in the global nuclear power generation industry, with China leading the charge.

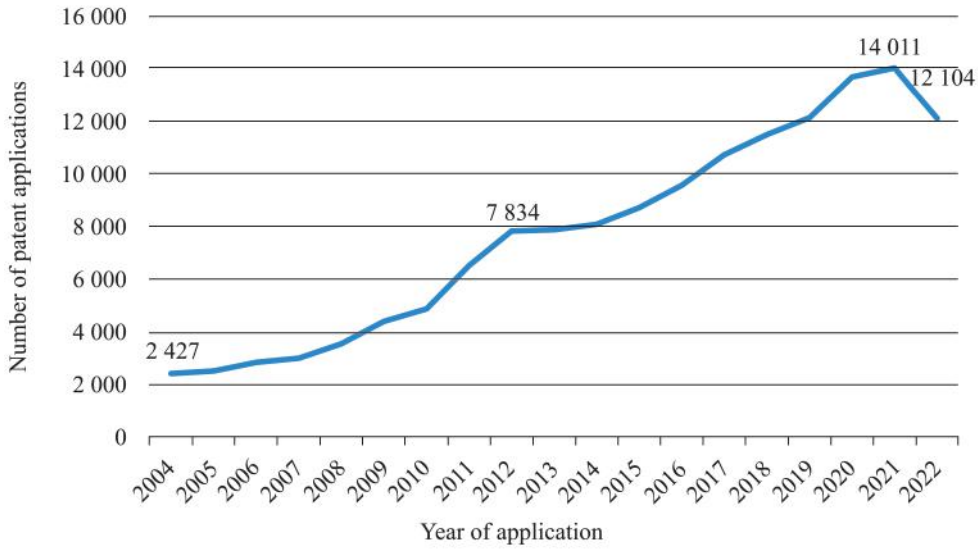

Figure 49 Global Trends in Patent Applications Related to the Nuclear Power Generation Industry (Item)

Source: PatSnap

① Note: Data from Taiwan (China) is not included.

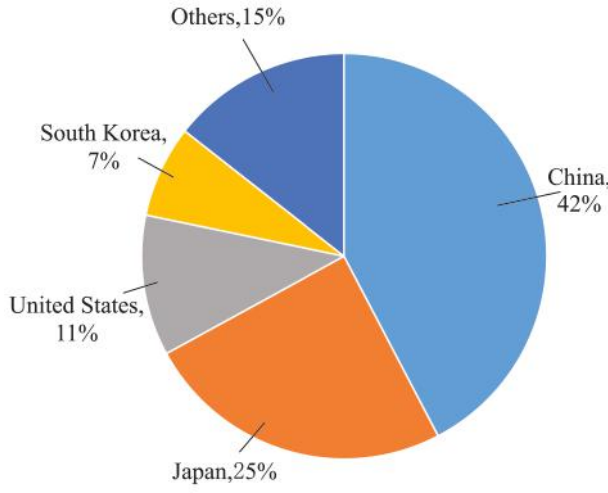

Figure 50 Geographical Distribution of Major Technological Contributors in the Global Nuclear Power Generation Industry

(Source: PatSnap)

ii. Impact of Disruptive Technological Innovation

The evolution of nuclear power technology can be divided into four generations, with the third-generation (Gen III) nuclear power technology currently the mainstream nuclear power technology for commercial use. Gen III nuclear power reactors include the AP1000 reactor from the US, the EPR from France, the VVER from Russia and the Hualong One from (and independently developed by) China. Currently, since global research on Gen III nuclear power technology is generally sufficient and Gen IV nuclear power technology could potentially be the next center of competition between major powers, competitive countries in nuclear power generation are taking the initiative in the R&D and application of Gen IV nuclear power systems.

Compared with Gen III nuclear power systems, Gen IV nuclear energy systems are more advanced and feature enhanced safety, higher economic competitiveness, less waste and higher proliferation resistance. Gen IV nuclear energy technology is currently in the prototype R&D stage. The GEN IV International Forum (GIF) selected six Gen IV nuclear fission reactor technologies for further research and development: Gas-cooled Fast Reactors (GFR), Lead-cooled Fast Reactors (LFR), Sodium-cooled Fast Reactors (SFR), Molten Salt Reactors (MSR), Supercritical Water-cooled Reactors (SCWR) and Very High Temperature Reactors (VHTR)①.

① Note: Source: In-depth Serial Reports on the Nuclear Power Industry (Topsperity Securities).

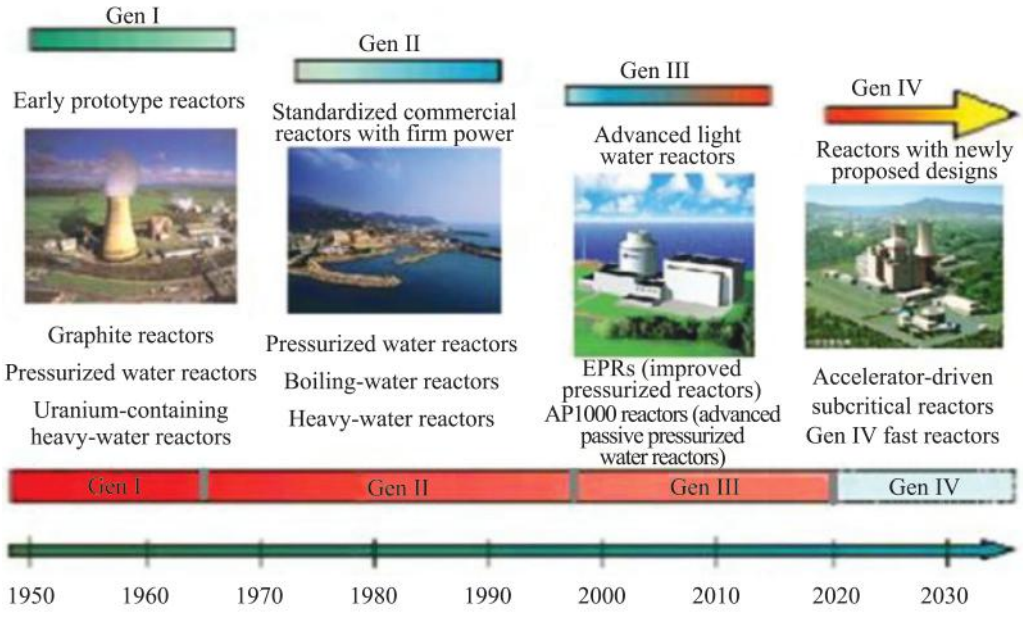

Figure 51 Timeline and Main Features of the Four Generations of Nuclear Power Plants

1. SFR

The SFR is a Gen IV reactor that uses liquid sodium as its coolant, enabling the highly secure operation of reactor cores and a higher speed of fuel regeneration than that of fuel consumption, while also facilitating easier actinide management by effectively fissioning long-lived actinides generated by reactor operations into fission products with shorter half-lives. The small SFR has advantages such as high power density, good inherent safety, good small-sized performance and an operating life that doesn't require refueling. Also applicable in remote areas such as ocean islands and islets and able to couple with new energy such as wind and photovoltaic energy to improve the stability of the micro-grid, it serves as one of the optimal technological routes for small advanced reactors and one of the main reactor types of Gen IV nuclear energy systems.

(1) Development Status of the SFR

The US built the world's first experimental fast reactor in the 1940s. It has built 22 fast reactors to date, including 19 SFRs, and is capable of exemplary manufacturing of fast reactor fuels. Russia (including the former Soviet Union) has been engaging in the R&D of fast-neutron reactors since the early 1950s. As the world's largest SFR in operation, the Russian-built BN-800 reactor began commercial power production in 2016. For France, the history of fast-neutron reactors started in 1953, and the relevant research is concentrated on the sodium-cooled system. France has built Rapsodie (an experimental reactor) and Phénix

(a prototype-reactor-based power plant).

As for the Asia-Pacific region, Japan has built two reactors, Jōyō and Monju. China is the eighth country in the world to have SFR technology. By following the development route for SFR technology of "experimental reactors—demonstration reactors—commercial reactors", China has completed an experimental SFR project and is currently building a 600 MW demonstration reactor.

It can be seen from global trends in SFR-related patent applications that during the past two decades, an overall trend of growth has been maintained despite fluctuations in the number of annual applications. Fluctuations in the number of patent applications were especially significant between 2011 and 2016 due to the Fukushima Daiichi Nuclear Accident. Since 2016, this number has continued to increase every year. As for 2022, although the number of patent applications has not yet been disclosed, initial query results indicate that the number of patent applications was less than expected. Since this field is still in the R&D and experimental stage, fluctuations in the number of technology R&D and patent applications are inevitable during the development process. However, since SFR is the first choice of GEN IV reactors and has the most robust technological base, the expectation is that the number of patent applications in this field will continue to increase in the future.

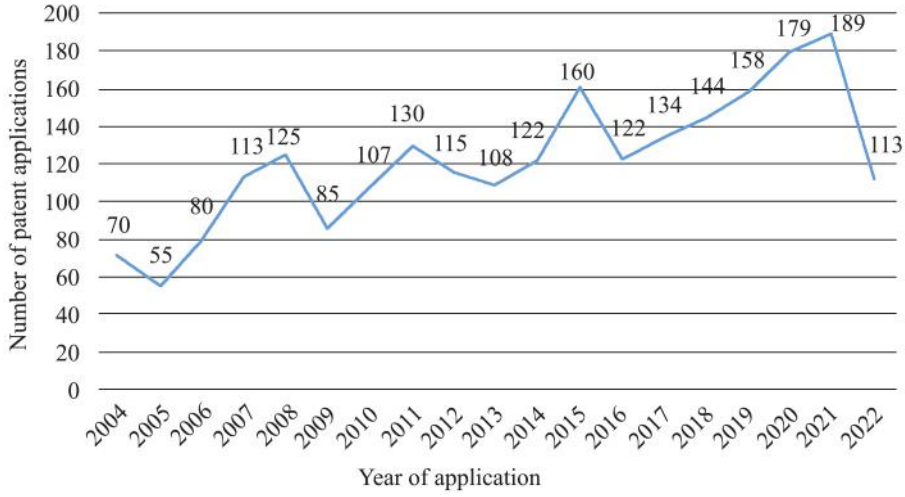

Figure 52 Global Trends in SFR-related Patent Applications (Item)

(Source: PatSnap)

(2) Technology Development Trends

The SFR is the most well-developed fast-neutron reactor technology and has two major advantages, namely fuel breeding and waste transmutation. To maintain fast neutrons in reactor cores, the coolant should not contain any light nuclei other than gases. Sodium,

helium and lead are all available options. The SFR is the most well-developed and nearest-term deployable type of Gen IV fast reactor.

Unlike pressurized water reactors, SFRs simply have to maintain the coolant at a temperature of less than 883℃ (sodium's boiling point) with the pressure at a level that is not too high. The biggest problem with SFRs is that sodium reacts violently when it comes into contact with air or water, and this can cause coolant leaks that lead to fires. SFRs can be arranged in a compact loop layout (loop-type SFR) or a pool layout (pool-type SFR). Further research shall be conducted in the future regarding the structure of the two different systems.

2. MSR

As one of six Gen IV nuclear power reactor candidates, the MSR is different from other solid-fueled reactor types. The earliest type of MSR used uranium or thorium dissolved in high-temperature molten fluoride salt as its fuel. MSRs have developed into two subclasses, namely Liquid Fueled MSR (MSR-LF) and Solid Fueled MSR (MSR-SF), the latter of which is also known as a Fluoride Salt-cooled High-temperature Reactor (FHR). Since the characteristics of MSRs include high temperature, low pressure, high chemical stability and high heat capacity in terms of heat transfer, this means that MSRs are suitable for commercial use in normal-pressure, compact, lightweight and low-cost conditions. Moreover, since the output temperature of an MSR can exceed 700°C, MSRs can be used for power generation, industrial production, high-temperature hydrogen production and methanol production through carbon dioxide absorption, thereby using nuclear energy in a comprehensive way.

(1) Development Status of MSRs

Since 2001, when the MSR was selected by the GIF as one of six Gen IV reactor candidates, research on thorium-based MSR (TMSR) has surged worldwide. European and North American countries have taken the initiative in terms of promoting international cooperation and establishing collaborative institutions to conduct conceptual design and evaluation of MSRs. Since 2001, the EU has launched a number of research projects with the participation of the European Atomic Energy Community (Euratom) and six EU countries. These projects have focused on evaluations and feasibility studies related to MSR-LF, as well as proposals for optimized designs of MSR systems.

As for the Asia-Pacific region, India and Japan are actively promoting research on TMSR-LF, while South Korea has launched a research program on MSR-SF. In 2011, China launched a special technological program on MSRs with the plan of becoming, within approximately 20 years, the first country to achieve the application of TMRs. At the same time, China also sought to establish the corresponding industrial chain and technological teams. In June 2023, China's National Nuclear Safety Administration issued a notice on licensing for the operation of the 2MWt experimental TMSR-LF, approving the operation of the experimental TMSR-LF in Gansu Province. This signaled that China's second Gen IV

nuclear power reactor was about to be put into operation after high-temperature, gas-cooled reactors.

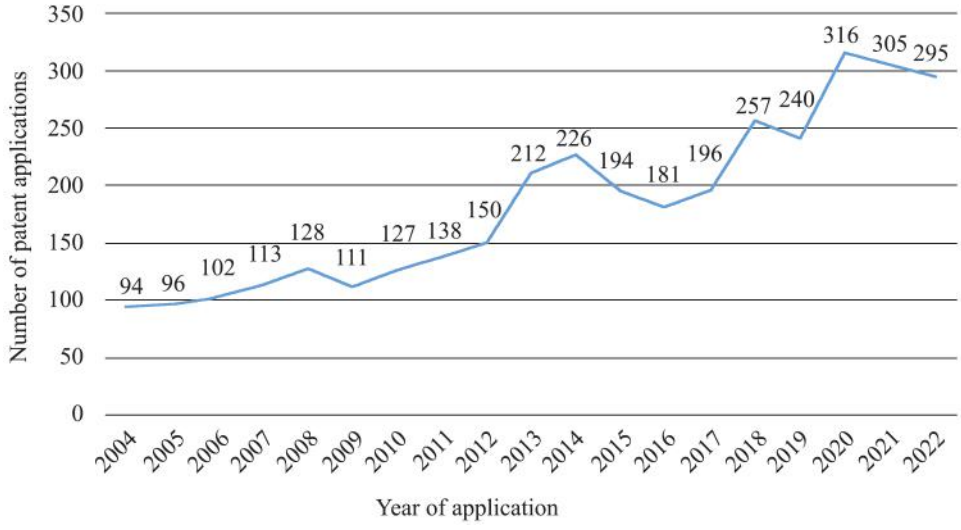

Figure 53 Global Trends in MSR-related Patent Applications (Item)

(Source: PatSnap)

It can be seen from global trends in SFR-related patent applications that during the past two decades, an overall trend of growth has been maintained despite fluctuations (which were particularly significant between 2012 and 2019) in the number of annual applications. The number of patent applications reached its peak (316) in 2020, and has been declining since. As for 2022, although the number of patent applications has not yet been disclosed, initial query results indicate that the number of patent applications was less than expected. Since this field is still in the R&D and experimental stage, fluctuations in the number of technology R&D and patent applications are inevitable. However, thanks to technological development and increased investment worldwide, the expectation is that the number of patent applications in this field will continue to increase in the future.

(2) Technology Development Trends

MSRs use molten salt as their coolant and do not have the issue of melting cores. Moreover, molten salt's low vapor pressure also reduces the likelihood of Break Loss-of-Coolant Accidents (BLOCAs). Additionally, if the core temperature exceeds the alert threshold, Freeze Plugs at the bottom will be melted automatically so that the molten salt can flow into the emergency draining tank for cooling without causing any nuclear pollution. MSRs can use thorium-based nuclear fuels. While the reserves of thorium-based nuclear fuels are higher than those of uranium-based nuclear fuels, thorium-based nuclear fuels are more suitable for civil use than for weapons manufacturing.

The TMSR-LF is highly economical, safe, sustainable and proliferation-resistant, and is

therefore highly feasible based on current technology. However, in light of the high operating temperature of the TMSR-LF, the strong corrosiveness of molten salt and the relative immaturity of the reprocessing technology, further research is needed on reactor designs and safety analysis methods, continuous on-line reprocessing technology for fuel salts, and reactor-related materials and manufacturing processes.

Ⅲ. Smart Energy

Practices of the smart energy industry in its current phase focus on the industry's intelligent transition. Smart energy technologies and solutions are new business forms and models that are based on the innovative integration of energy technology and Internet information technology, as well as supporting technical services.

ⅰ. Development Trends and Regional Competitiveness

1. Smart Energy Facilitates the Establishment of an Energy Ecosystem Where the Internet of Things Seamlessly Connects with the Internet of Services.

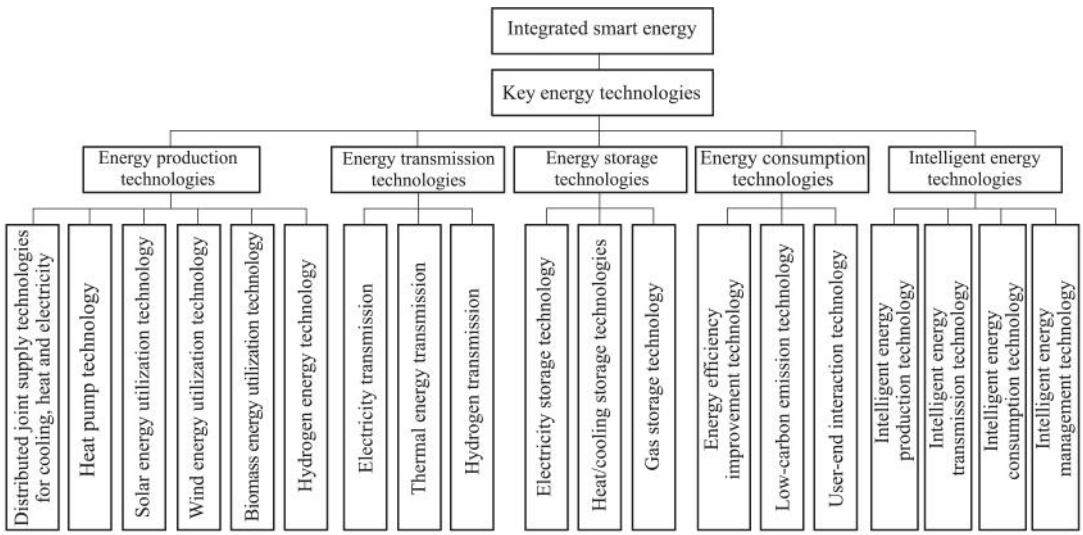

Figure 54 Structure of the Smart Energy System

The smart energy system, whose structure is as shown in Figure 54, focuses on digital and intelligent energy production, storage, supply, consumption, management and services. It seeks horizontal coordination between multiple energy products (electricity supply, heat supply, cooling, water supply and hydrogen supply) and multiple energy supply modes (hydroelectricity, thermo-electricity, nuclear power, wind power, PV electricity and electricity storage) so as to achieve interactive optimization among energy processes such as power sources, the power grid, the power grid load, power storage and power consumption,

to provide end-users with integrated energy solutions and to facilitate the establishment of an energy ecosystem where the Internet of things seamlessly connects with the Internet of Services.

2. The Energy Industry Is Basically Undergoing an Intelligent Transition from an Information-based Stage

Currently, the energy industry is basically undergoing an intelligent transition from an information-based stage. However, in this transition the progress of different types of energy systems differs due to differences in their characteristics. With a solid informatization basis and active ongoing efforts to achieve innovation in terms of the integration of digital technologies that facilitate the ubiquitous Internet of things, the electrical power system has entered a stage of energy intelligentization and become an advanced energy system in terms of energy digitization.

Digital technologies provide assistance to the energy industry in the form of cost reductions and efficiency improvements. The IEA made a forecast in *Digitization and Energy* that the widespread use of digital technologies could decrease oil and gas production costs by 10-20%. Moreover, digital technologies might be able to reduce the curtailment of solar photovoltaics and wind power from 7% to 1.6% by 2040, preventing 30 million tons of carbon dioxide emissions in the years up to 2040. Meanwhile, digitization can also benefit specific clean energy technologies like carbon capture and storage (CCS). Currently, various countries around the world are taking measures to promote digitization and apply digital technologies such as big data analysis & machine learning, blockchain, distributed energy management and cloud computing to energy-related processes such as energy production, transmission, trading, consumption and regulation.

3. The Smart Energy Industry Has Basically Seen a Trend of Growth in Patent Applications, with Asia Becoming the Main Technological Source

The following figure shows development trends in the smart energy industry worldwide by analyzing patent data. Technological innovation in the smart energy industry has advanced rapidly during the past two decades. In 2004 there were only 2,649 patent applications, but by 2022 this number had surged to 45,286, more than a 10-fold increase. The overall trend of patent applications in the global smart energy industry is evidently one of rapid growth. Currently, the world is paying more and more attention to smart energy. The expectation is that the number of patent applications in this sector will continue to increase in the future.

The figure above shows the distribution of technological source countries for the global smart energy industry in terms of patents. It shows that China has the largest number of patent applications, accounting for approximately 74% of the global total. This is far more than for any other country, indicating that China is the largest technological source country

for the global smart energy industry. Meanwhile, Japan ranks second with approximately 7% of the share of the global total, while the US and South Korea rank third and fourth respectively, with both their shares at less than 5% of the global total. Consequently, Asian countries, especially China, Japan and South Korea, exhibit strong technological competitiveness and innovative ability in the global smart energy industry, with China leading the charge.

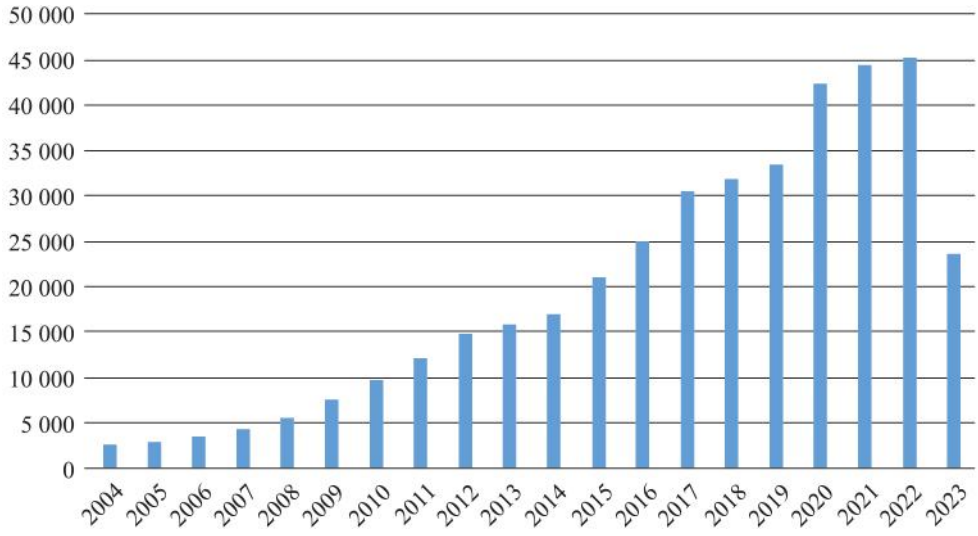

Figure 55 Global Trends in Patent Applications Related to the Smart Energy Industry (Item)

(Source: PatSnap)

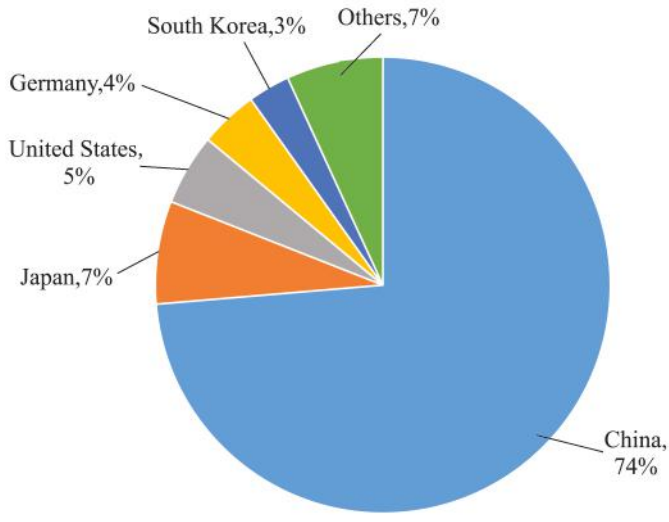

Figure 56 Geographical Distribution of Major Technology Contributors in the Global Smart Energy Industry

(Source: PatSnap)

ii. Impact of Disruptive Technological Innovation

Smart energy uses technologies such as the Internet of things, big data, multi-objective optimization and artificial intelligence to do real-time monitoring, analysis, and calculations of business data, performance data and operational data in the processes of energy production, dispatching, transmission, distribution, storage, sales and use. This makes it possible to realize energy forecasting, multi-parameter optimization and closed-loop regulation, promoting the in-depth integration of energy and informatization, facilitating intelligent energy production, transportation, consumption and management, and enabling predictive maintenance by fault diagnosis, thus improving energy efficiency and ensuring safe and stable system operations.

Continuous innovation in smart energy has been introduced in multiple application scenarios such as smart production, smart marketing and smart management①.

1. Smart Production

Since the energy industry is an asset-intensive industry with characteristics such as costly equipment, long industrial chains, high risks and strict environmental requirements, its common pain points include opaque equipment management, difficulties in process and knowledge inheritance, low levels of upstream and downstream coordination in the industrial chain and high pressure on safe production. Given the changes in the world's energy landscape, energy development is undergoing a low-carbon, decentralized and intelligent transition. Changing demand in the market of energy consumption services has forced energy production, storage and transportation to become safer, more efficient and cleaner. Therefore, energy production processes should be made more intelligent by relying on digital technologies.

(1) Intelligent Boiler Alerts for Power Plants

Currently, unscheduled outage times at power plants in China that are due to boiler tube leaks account for over 30% of the total annual outage time. Boiler tube leaks are the main cause of unscheduled outages in power generation units and have a considerable impact on the economic efficiency of boiler operations. Intelligent boiler alerts can judge whether there are any boiler tube leaks, achieve early detection and reporting of boiler tube leaks and identify the location and severity of leaks. This is done by detecting the operational status based on the power plant mechanism model and AI technology. Alerts provide data support for the predictive maintenance of relevant equipment, remove anomalies in equipment operation at an early stage, reduce unscheduled boiler halts, generator outages and corresponding energy consumption, and greatly improve the use efficiency of relevant equipment.

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① CCID Consulting. Smart Energy White Paper: Embracing the Digital Era and Creating New Opportunities for a New Future.

（2）Smart Safety Management

Energy companies have introduced personnel positioning systems to enable area segmentation and locate personnel based on 3D space modeling. These systems can link the safety precautions for each segment with the production and operation information of these segments, making it possible to provide intelligent assistance for on-site personnel in identifying dangerous areas and preventing accidents that cause human casualties. Currently, errors in personnel positioning can be controlled within a range of 20-50mm, making it possible to effectively prevent incorrect operations or accidental entry into the wrong segment. For example, some power plants set up virtual electronic fences by integrating information about personnel locations with 3D power plant models so that they can do real-time monitoring of important equipment and dangerous areas such as high-temperature and high-pressure areas. Smart safety management systems can help on-site production personnel identify dangerous areas, remind trespassers and safety supervisors to confirm their locations, ensure the safety of personnel and equipment and reduce unnecessary losses.

（3）New Energy Power Plants with "No Men on Duty and Fewer Men Standing Guard"

New energy, and big data innovation platforms are built based on Internet architecture by integrating AI, big data, cloud computing, the Internet of things, the mobile Internet and other technologies, enabling one-stop data collection, storage, services and operation. These platforms enable real-time collection of heterogeneous data from multiple sources including power sources, power grids and power grid loads, and real-time collection of minimum granularity component data from wind-driven generators and PV panels at a frequency of once per five to seven seconds, efficiently supporting the establishment and use of applications for various industries. In particular, these platforms have enabled a "no men on duty and fewer men standing watch" mode for multiple new energy power plants, assisting power plants in reducing personnel and improving efficiency. Currently, the "fewer men on watch" mode also extends to the design and construction of new energy power plants. Power generation companies rely on these platforms to innovate business models, change original work and business patterns and promote industrial upgrades.

（4）Intelligent Electric Power Inspections

The core task of electric power inspections lies in the operation and maintenance of power transmission and transformation equipment. Power enterprises use AI algorithms to improve the recognition accuracy of intelligent inspection robots for equipment images, greatly reducing the costs of operation and maintenance and further economizing the labor force. After pre-setting inspection points and planning inspection routes, intelligent inspection robots automatically use relevant meters to perform measurement and read the results, thereby

effectively reducing the workload of manual inspections, improving work efficiency, and reducing omissions. These robots even reduce errors caused by human factors and eliminate potential safety hazards to the greatest extent possible.

2. Smart Marketing

The application of information technologies such as artificial intelligence and big data has broken down the barriers between traditional industries and the "high walls" between different professional areas, and has also considerably changed the patterns of the energy industry. Traditional energy enterprises face challenges from new market players such as load integrators and many brand-new companies that were established based on the Internet ecosystem. Energy consumers will therefore become a more important force than ever in terms of reshaping the market landscape.

(1) Integrated Energy Services

New-generation information technologies are continuously breaking down barriers between traditional businesses, facilitating the integrated development of energy fields such as electricity, fuel gas and distributed energy that used to be independent of one another. Integrated energy services use artificial intelligence, cloud computing, the Internet of things and other information technologies to realize the in-depth integration of energy flows and information flows. In other words, they are energy supply service portfolios based on the integration of multiple heterogeneous energy sources (such as coal, petroleum, natural gas, electricity and heat) within a certain area, and are designed to meet diverse demands for energy consumption.

(2) Smart Power Grid Service Halls

Traditionally, when dealing with any electricity-related business users had to visit a service hall run by the corresponding power enterprise, and services could only be provided to them manually at service windows after their waiting numbers were called. With the application of smart service halls, users can now quickly be recognized by an intelligent system as soon as they step into a service hall. After their identities have been verified against their registered information in the system, the system will then automatically send them the relevant business information to be handled, such as electricity bills to be paid. If the system finds that a user has been waiting for a long time, a corresponding notice will automatically be sent to the mobile device of an on-site customer manager to remind him/her to actively provide services.

3. Smart Management

In terms of the management model, traditional enterprises improve production efficiency through strict and impartial management mechanisms and methods as well as standardized and procedure-based means. The development of digital technology has not only revitalized the

operation management of enterprises, but also disruptively impacted it. In the era of the digital economy and in the face of rapidly changing market demands and iterative technological methods, enterprises are required to undergo a data-driven transition from an experience-driven state and to agilely respond to market changes. They must also undergo a coordinated, development-oriented transition from a state of being independent from each other to a state of establishing operation procedures in response to digital innovation, and undergo an intelligent, digital transition from mechanisms that rely on labor forces and tiered management in order to improve both the efficiency and benefits of business control.

（1）Smart Supply Chain Management

Smart supply chain management incorporates all supply-related processes （from procurement to production and sales）of enterprises into a unified network or chain from a global, macroscopic, full product life-cycle perspective based on new-generation information technologies such as the Internet of things, the mobile Internet, artificial intelligence and big data, all while placing a focus on coordination between internal and external businesses. Moreover, visualization methods are used to display data and mobile methods are used to facilitate data access. In order to achieve smart supply chain management, a supply chain management cloud platform shall be established to facilitate the interconnectedness of all processes, enable information sharing between the supply side and the demand side, and efficiently coordinate the use of supplies. Meanwhile, scientific, reasonable supply classifications should be conducted, and reserve quota plans should be formulated based on the reserve principles of corresponding energy enterprises in order to ensure a reasonable number of supply categories and a reasonable volume of supply inventory. Moreover, depending on the actual statuses of the corresponding energy enterprises, the process layout in the supply chain should be optimized and the supply reserve areas should be classified into different levels. This will improve the capacity for supply guarantee and provision and effectively coordinate procurement, logistics management and the use and consumption of supplies in areas covered by corresponding grid systems. It will also effectively reduce the cost, improve the benefits and efficiency of the provision of reserved supplies and ensure safe production.

（2）Intelligent Collaborative Offices

Intelligent collaborative offices use the middle offices of enterprises to horizontally connect between different business processes and achieve cross-functional interconnection and collaboration. They are able to achieve the seamless integration of all business processes, public data, application software, hardware and standards of enterprises through the comprehensive integration of data layers, application systems, user interfaces and business processes. This then forms a management pattern that coordinates professional management

and resource management on an online basis, ensures smooth interdepartmental connectivity, reduces the time cost and economic cost of communication and information exchanges, and improves office efficiency. Furthermore, they enable various functions such as intelligent document review, auxiliary confidentiality setting, auxiliary signing and approval, automatic case closing, intelligent proofreading and inspection and error correction during the formulation, review, signing and approval and case handling of official documents. They do this by using AI technology to establish middle office knowledge systems based on document management. Additionally, they use artificial intelligence and big data technology to analyze administrative office and business data for enterprises and to automatically generate reports. This provides support for business management along with an objective and rational basis for business decisions.

Chapter Ⅶ
New Materials and Advanced Manufacturing

The importance of new materials has piqued the interest of countries around the world, motivating them to quickly adjust their industrial policies and accelerate the layout of cutting-edge materials and disruptive technologies. Major developed countries have also introduced special policies for key areas involving new materials, such as new display materials, new energy materials, and third-generation semiconductor materials, to accelerate research on, development of, and production of these key materials and to promote innovation in and development of advanced manufacturing.

Ⅰ. Key Materials for New and Renewable Sources of Energy

In 1981, the UN Conference on New and Renewable Sources of Energy held in Nairobi, Kenya described new energy and renewable energy as follows: Based on new technologies and new materials, traditional renewable energy is developed and utilized in a modern way, with fossil fuel-based energy that are limited in terms of the amount of resources and that cause environmental pollution constantly being replaced by renewable energy. Renewable energy mainly focuses on the development of solar energy, biomass energy, ocean energy, wind energy, geothermal energy and hydrogen energy. In recent years, thanks to a gradual improvement in people's environmental consciousness and the increasing prominence of the energy crisis, key materials for new and renewable sources of energy have received a great deal of attention. These are mainly materials that can be used to manufacture new and renewable sources of energy such as solar cells, wind turbines and electric vehicles. Not only can these materials improve the efficiency of energy use, but they can also reduce environmental pollution. This is highly significant when it comes to the sustainable development of society, both in the present and the future. The key materials used in new and renewable sources of energy are shown in the figure below.

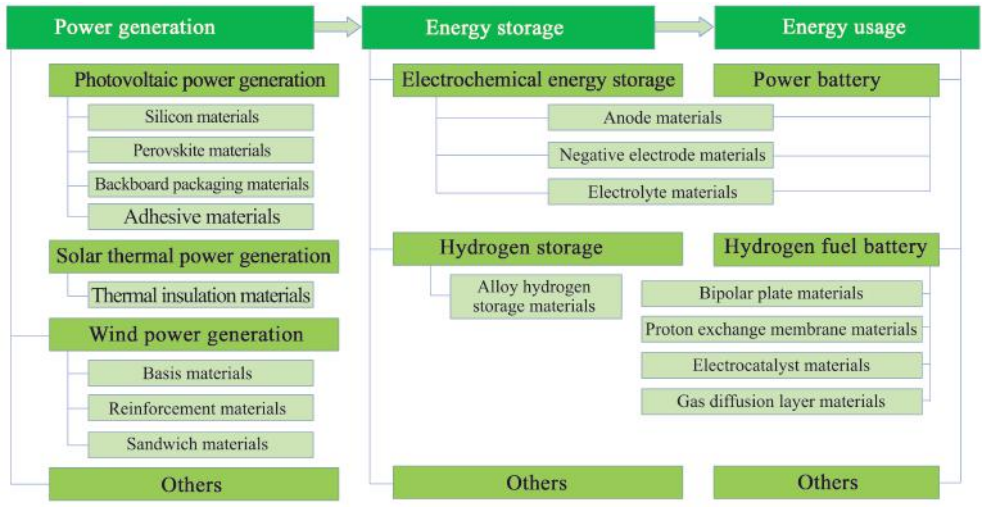

Figure 57 Summary of Key Materials for New and Renewable Sources of Energy

(Source: Qi Dian New Materials)

i. Development Trends and Regional Competitiveness

1. The Development of Key Materials for New Energy and Renewable Sources of Energy Has Contributed to the Growing Market Scale of the Global New Materials Industry

In 2021, the scale of the global industry for new materials exceeded USD 3 trillion, with an annual compound growth rate of approximately 8% from 2017 to 2021. With the development of downstream emerging industries such as the new energy industry, as well as the increasing demand for key materials, the scale of the global market for the new materials industry is expected to continue growing. It is expected to reach USD 3.72 trillion by 2023.

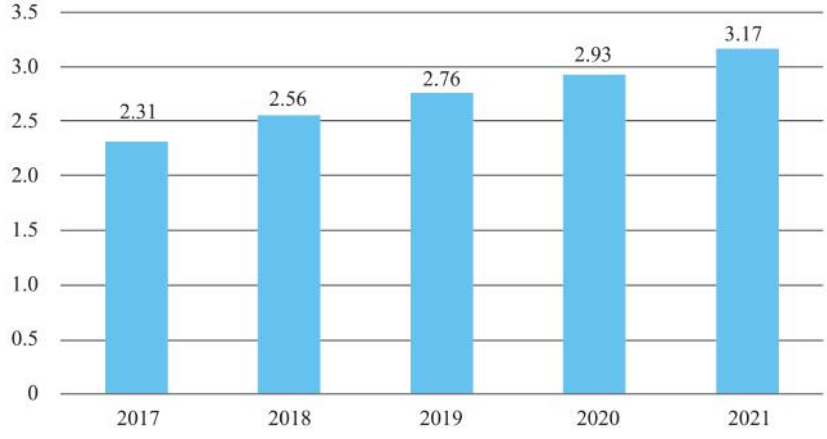

Figure 58 Scale of the Global Market for the New Materials Industry for 2017-2021 (In USD Trillion)

(Source: www.hsmap.com)

2. New Energy Enterprises Have Accelerated the Development of Key Materials, Resulting in a Significant Increase in Revenue

Global new energy companies have accelerated the development of key materials for new and renewable sources of energy. Thanks to the stimulation of market demand, enterprises' overall revenue has increased significantly. In 2023, the total revenue of global new energy enterprises exceeded RMB 10 trillion. Of these, the total revenue of the top 500 enterprises reached RMB 8.66 trillion, representing a year-on-year growth rate of 57.74% and a substantial increase of RMB 3.17 trillion over the previous year's figure of RMB 5.49 trillion. The industrial scale also achieved explosive growth.

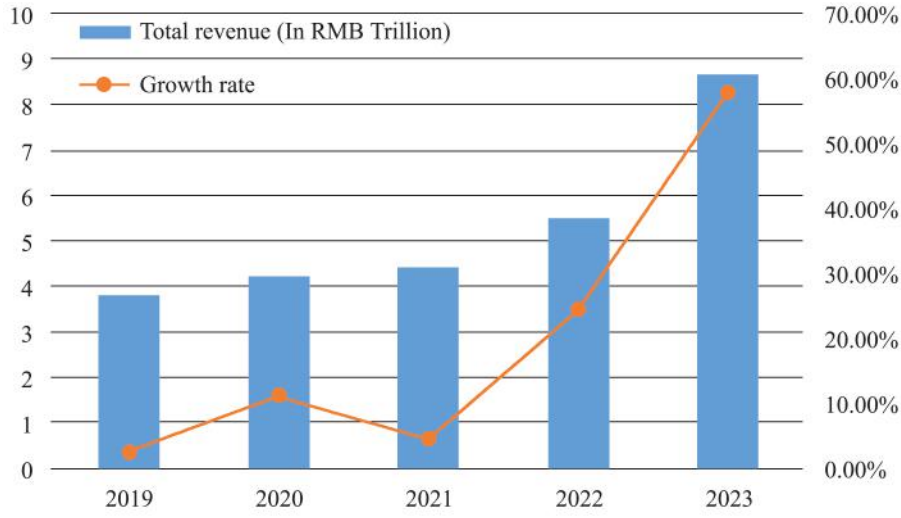

Figure 59 Total Revenue of the Top 500 New Energy Enterprises from 2019 to 2023 (In RMB Trillion)

(Source: www.xincailiao123.com)

3. The Number of Patent Applications in the Field of Key Materials for New Energy and Renewable Sources of Energy Is Growing Rapidly

In the past two decades, patent applications in the field of key materials for new and renewable sources of energy have grown continuously. As the global demand for renewable energy sources continues to increase, the demand for key materials is also growing, and the types of key materials are also increasing. As shown in the figure, the number of global patent applications in the field of key materials for new and renewable sources of energy was less than 2,500 in 2004, but increased by more than five times to reach 13,825 in 2020.

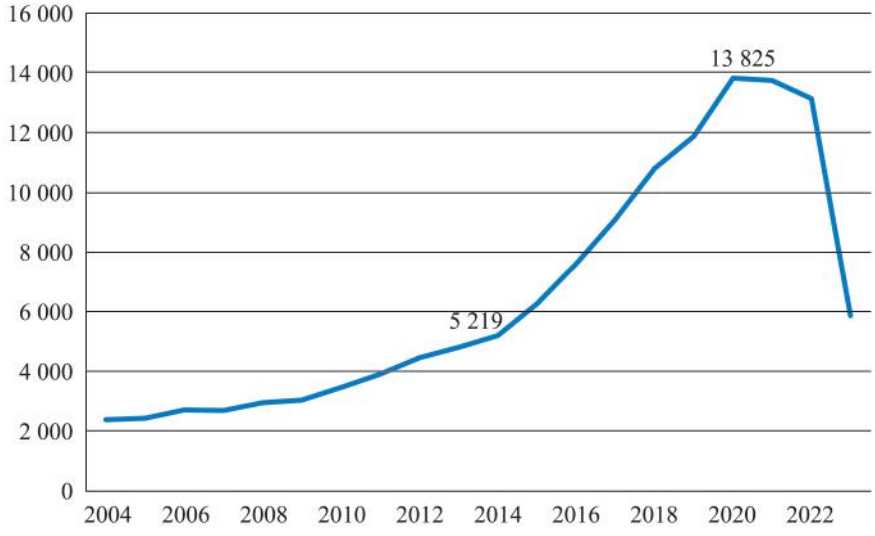

Figure 60 Trends in Patent Applications in the Field of Key Materials for New Energy and Renewable Sources of Energy

(Source: PatSnap)

4. Technology in the Key Materials Field of New and Renewable Sources of Energy Globally Is Mainly Derived from Asia

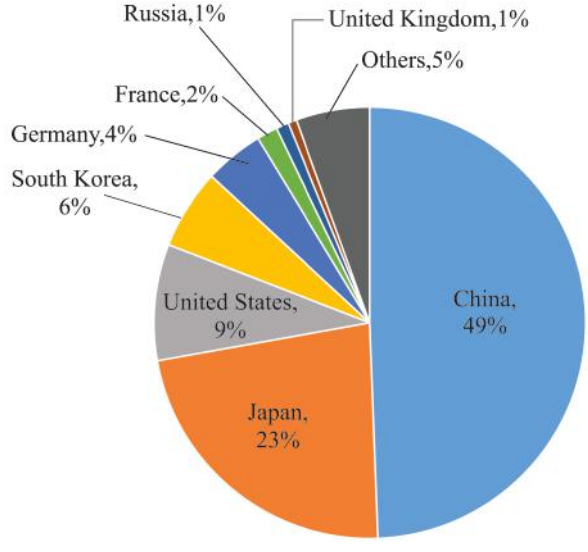

Figure 61 Distribution of Technical Sources in Key Materials for New and Renewable Sources of Energy

(Source: PatSnap)

The figure shows the global distribution of technology source countries in the field of key materials for new energy and renewable sources of energy. Of these countries, China

accounts for 49% of patent applications while Japan and South Korea also rank relatively high in Asia, accounting for 23% and 6% of patent applications respectively. China, as a representative country of Asia, has the world's largest energy consumption market as well as the most active environment for technological innovation. Thanks to governments at all levels promoting it, China also has very active technological innovation of key materials for new energy and renewable sources of energy.

ii. Impact of Disruptive Technological Innovation

1. Materials for Perovskite Solar Cells

(1) Thanks to Its Excellent Performance, Perovskite Materials Have Attracted Much Attention in the Field of Solar Cells

The technology of making perovskite solar cells is a new type of solar cell technology that has attracted much attention in recent years. These are a type of solar cell that uses perovskite materials as photoelectric conversion layers to promote electronic transitions in semiconductor materials through photon energy, thereby generating currents. Perovskite materials have a high light absorption coefficient and good carrier transmission characteristics, which can effectively improve the conversion efficiency of solar cells. With continuously improving technology and steadily falling costs, perovskite solar cells are expected to become the leader of the future solar cell market.

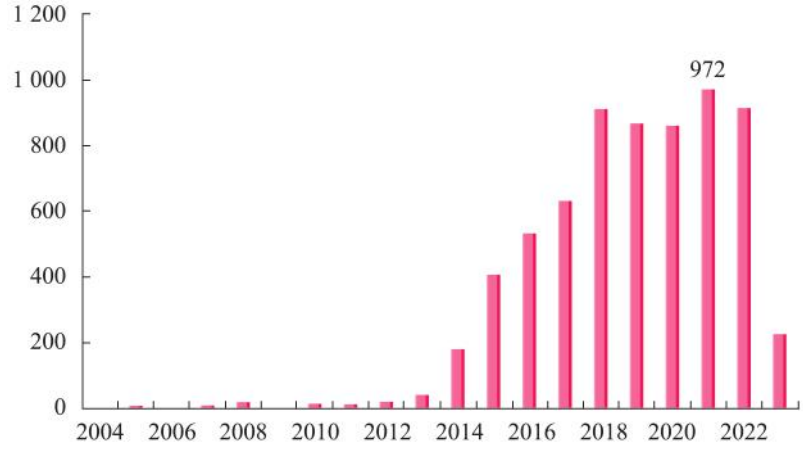

Figure 62 Global Trends in Patent Applications Related to Perovskite Cell Materials (Item)

(Source: PatSnap)

Continuously developing and mature technology will promote perovskite solar cells and help their market share continue to expand. According to BCC Research, the global perovskite solar cell market will be worth USD 7.2 billion by 2025. The Asia-Pacific region

will dominate this market, with its value expected to account for approximately 44% ① of the entire perovskite solar cell market worldwide. As of the end of February 2023, China has put into operation three perovskite cell production lines with a production capacity of more than 100 megawatts, namely Golden Concord Holdings Limited, Hangzhou Microquanta Co. Ltd., and UtmoLight Co., Ltd. ②

(2) In the Past Decade, Patent Applications in the Field of Perovskite Cell Materials Have Soared

Perovskites gained recognition relatively late. In 2009, Tsutomu Miyasaka, a distinguished professor at the Toin University of Yokohama in Japan, discovered that perovskite has a special photoelectric effect. Since this discovery, perovskite materials have rapidly developed. Proposals put forth in the relevant policies of various countries have greatly promoted the development of this field. Japan's 2021 *Act on Promotion of Global Warming Countermeasures* specifies the development of the next generation of basic solar cell technology. Meanwhile, in 2022 the U. S. Department of Energy made a proposal to provide USD 2,900 million in funding for recyclable solar technology and to commercialize perovskite photovoltaic technology, while in 2023 China publicly solicited proposals for new standards in the field of perovskite photovoltaic cells in order to promote the standardization of perovskite solar cells. Looking at the global trend in patent applications in the field of perovskite cell materials, one can see that there were very few patent applications in this field before 2014. However, the number of annual global patent applications began to increase rapidly after that from less than 200 in 2014 to 972 in 2021. Thanks in part to government support, the expectation is that patent applications in the field of perovskite cell materials will continue to grow.

(3) Future Directions of Research ③

The stability of perovskite materials needs to be improved. Perovskite materials must be made more stable. These materials have an ionic bond structure, which means that compared with the covalent bond of crystalline silicon materials, perovskite materials are more prone to decomposition and ion migration, which leads to their instability. This instability can generally be solved by adjusting the material formulation and optimizing the battery structure. One way of doing this is by doping other ions to stabilize the lattice and designing special passivation layers to reduce ion migration.

Perovskite layer films are neither uniform enough nor dense enough when prepared in a

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① Analysis Report on the Prospects for Perovskite Batteries. https://m.toutiao.com/is/iRyd8rL8/.

② Future Think-tank-New Photovoltaic Cells, the Start of Industrialization. https://baijiahao.baidu.com/s?id=1773075913261992353&wfr=spider&for=pc.

③ The mainstream technology routes, film preparation, and three major pain points for Perovskite Batteries, https://www.thepaper.cn/newsDetail_forward_23085079.

large area. Solving this problem requires a combination of equipment, process, and materials. In terms of materials, elements such as cesium, tin, bromine, and chlorine can be added, though the material system must be continuously optimized to improve its efficiency and stability.

The preparation process of perovskite film must be improved. In the production of perovskite solar cells, the three core processes are coating, laser etching, and packaging. The most important of these is the preparation of perovskite film. Technical research focuses on how to prepare uniform and non-porous perovskite film on large-area substrate.

2. Proton Exchange Membranes

A proton-exchange membrane (PEM), also known as a proton or hydrogen ion exchange membrane, is a dense ion-selective membrane. In recent years, with the development of new energy technologies such as fuel cells and flow cells, PEMs have become the key materials in the field of new energy. They are widely used in the field of water electrolysis for hydrogen production, fuel cells and all-vanadium redox flow batteries.

(1) The Market for Global Proton Exchange Membranes Is Growing Steadily, with North America as the Largest Consumer Market

In 2022, the global PEM market reached USD 1,139.92 million in sales. This market is expected to reach USD 2,530.81 million by 2028, with an annual compound growth rate (CAGR) of 14.22% during this period (2022-2028).

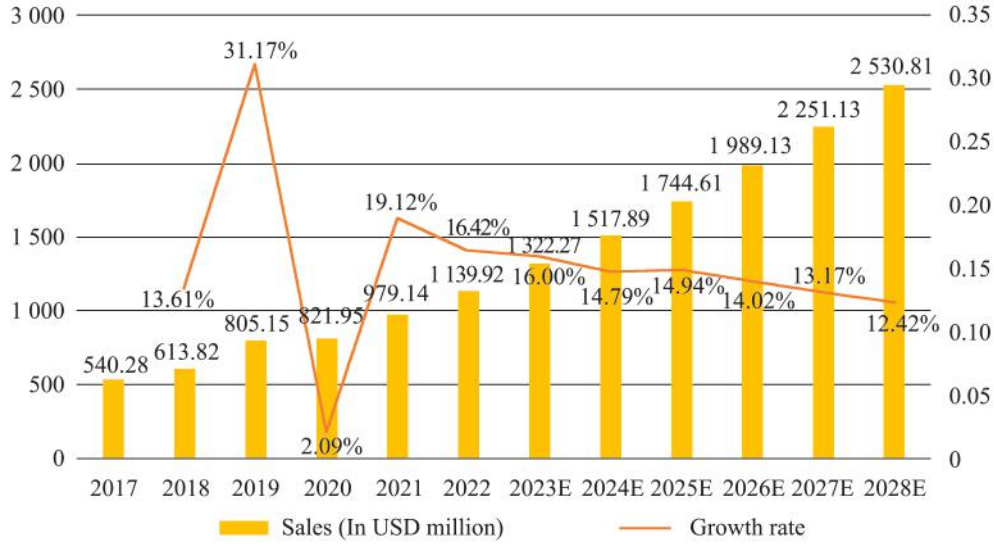

Figure 63 Global Output Value and Development Trend of Proton Exchange Membranes

(Source: QYResearch)

In terms of product type, perfluorosulfonic acid PEMs are currently the most widely used both in China and elsewhere, with a market share of 89.67% in 2021 and a market revenue of USD 877.96 million. In terms of applications, fuel cells had a market share of

approximately 74.78% in 2021, with revenue of USD 732.15 million. A compound growth rate of approximately 14.69% is expected in the coming years (2022-2028).

In terms of consumption, North America is currently the world's largest consumer market with a market share of 32.61% in 2021, followed by China and Europe with market shares of 26.60% and 21.95% respectively.

The figure shows the trend of patent applications in the field of PEMs in the Asia-Pacific region as well as other regions. The global PEM field started almost the same as fuel cells, with Europe and the United States (represented by the United States) holding a technological monopoly in this field. As can be seen from the figure, other economies outside the Asian-Pacific region got an earlier start in the field of PEMs, with a larger number of patent applications before 2004. Over time, the number of patent applications in other economies in this field has gradually decreased. In the past decade, the Asia-Pacific region (represented by China) has experienced rapid development in the field of PEMs, and research and development achievements have also begun to indicate that China's domestic PEMs are now comparable to similar products in other countries in terms of proton conductivity and gas permeability. As for trends in patent applications, the number of patent applications in the Asia-Pacific region has risen significantly in the past decade, with nearly 300 such patent applications in 2022.

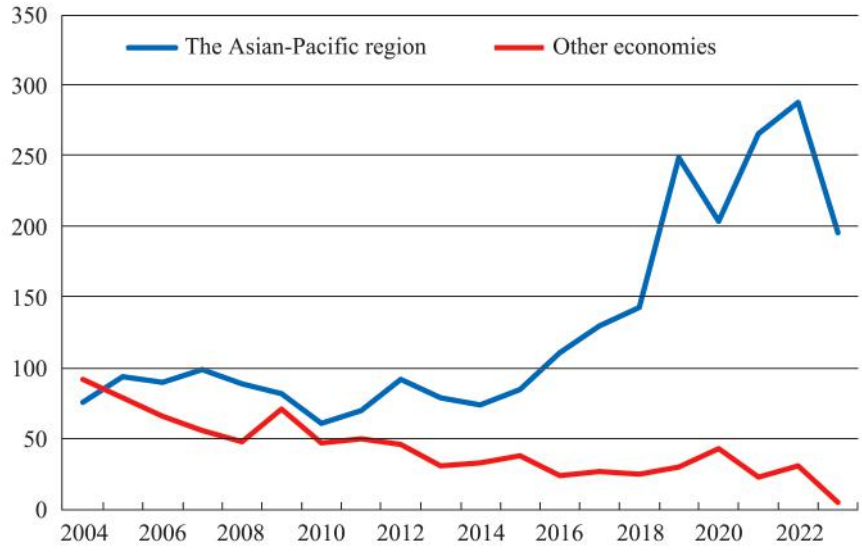

Figure 64 Global Trends in Patent Applications Related to Proton-exchange Membranes (Item)

(Source: PatSnap)

(2) Technological Development Trends

Nowadays, PEM-related research and development trends mainly include six aspects, the first of which is material improvement. The improvement and optimization of PEM materials

is an area of focus, and mainly includes improving efficiency, enhancing stability, and reducing costs. The second of these aspects is structural optimization. Structure optimization design is one of the key factors affecting the performance of PEMs. Current research mainly focuses on the optimization of membrane structures, the adjustment of membrane thickness, and the grading of membrane surfaces. The third one is the reaction mechanism, the study of which is the basis for improving the performance of PEMs. Currently, this mainly focuses on the proton conduction mechanism and electrochemical characteristics of membranes. The fourth one is high-temperature applications. The application of PEMs under high-temperature conditions is one of the most exciting areas of recent research. Under high-temperature conditions, the performance of PEMs improves, for instance in the form of more efficient electrocatalytic water electrolysis. The fifth one is composite materials. Composite materials can improve the properties of PEMs, for example, their electrical conductivity and flame retardant properties. The sixth one is sustainability. Sustainability includes aspects such as environmental friendliness, low energy consumption, and recyclability①.

Ⅱ. Third Generation Semiconductors

Third-generation semiconductors refer to semiconductor materials that have a bandgap width greater than 2.2 eV, such as gallium nitride, silicon carbide, and zinc oxide. Compared with silicon and germanium, which are used as first and second-generation semiconductor materials, third-generation semiconductor materials have performance advantages such as a higher breakdown electric field, higher thermal conductivity, and a higher electron saturation rate. They are widely used in high-power, high-frequency, high-temperature electronic devices, LED lighting, and electric vehicles.

ⅰ. Development Trends and Regional Competitiveness

1. The Penetration Rate of Third-generation Semiconductor Materials Has Been Increasing Year by Year, and Europe with the United States Having Obvious Advantages in This Field

Core third-generation semiconductor materials like silicon carbide and gallium nitride are both experiencing a stage of rapid development. The first generation of semiconductors, represented by silicon materials, still accounts for 90% of the total market share. The combined market share of second- and third-generation semiconductors is less than 10%,

① Zhang, Y. Study on the development status of key materials for hydrogen fuel cells. Proceedings of the Chinese Materials Conference from 2022 to 2023. 8-13.

with these semiconductors mainly being used as market supplements. The penetration rate of third-generation semiconductor materials is increasing year by year and is expected to approach 5% in 2023. The penetration rate of third-generation semiconductors used in power components continues to rise in various fields, and the rapid development of 800 V automotive electric drive systems, high-voltage charging piles, consumer electronics adapters, data centers, and communication base station power supplies pushed up the market demand for silicon carbide and gallium nitride power semiconductors in 2022. According to Yole, the penetration rate of third-generation semiconductors has been increasing year by year. In 2023, the penetration rate of silicon carbide is expected to have reached 3.75% and the penetration rate of gallium nitride is expected to have reached 1.0%, implying that the total penetration rate of third-generation semiconductors is expected to have reached 4.75%.

In 2022, the United States continued to maintain its dominant position in the third-generation semiconductor industry, with Cree, II-VI, Dow Corning, Transphorm, and several other top global companies accounting for 80% of the world's silicon carbide production. Europe has a complete industrial chain of silicon carbide substrates, epitaxy, devices, and applications, along with unique high-end lithography machine manufacturing technology and manufacturers with advantageous positions such as Infineon, STMicroelectronics, Siltronic, and IQE.

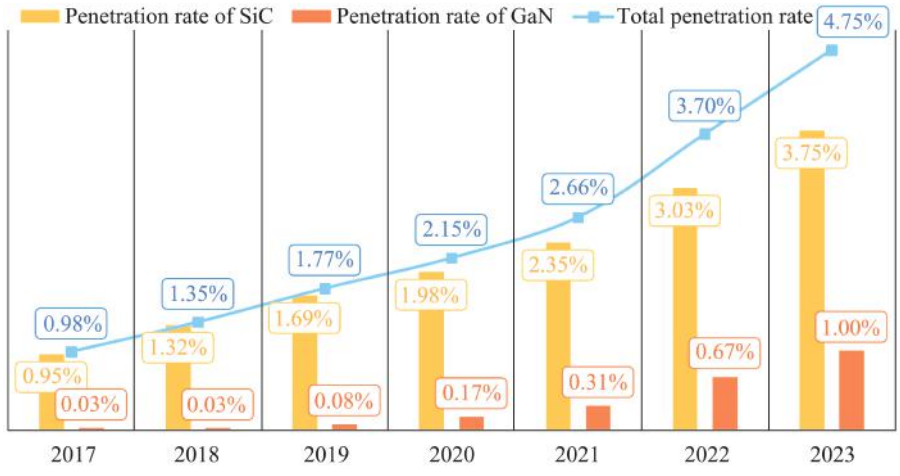

Figure 65 Global Penetration Rates and Predictions of Major Third-generation Semiconductor Materials Worldwide

(Source: Yole Intelligence)

2. Global Patent Applications Related to Third-Generation Semiconductors Have Grown Rapidly in Recent Years, with the Asia-Pacific Region as the Main Source of Patent Technology

The global trend of patent applications related to third-generation semiconductors is shown

in the above figure. Over the past two decades, technological innovation in the industry has generally experienced a trend of rapid development, with growth being particularly rapid in the years since 2019. Looking at the distribution of technology source countries in the field of third-generation semiconductors globally, China has the largest number of patent applications and accounts for about 43.5% of the global total, far more than any other country. China is also the world's largest source of technology when it comes to third-generation semiconductors. Japan ranks second with 26.4% of the world's patent applications related to third-generation semiconductors, and South Korea ranks fourth with about 4.6% of such applications. Globally, in the field of third-generation semiconductors, it is clear that Asian countries, represented by China, Japan and South Korea, have strong technological competitiveness and innovation capabilities.

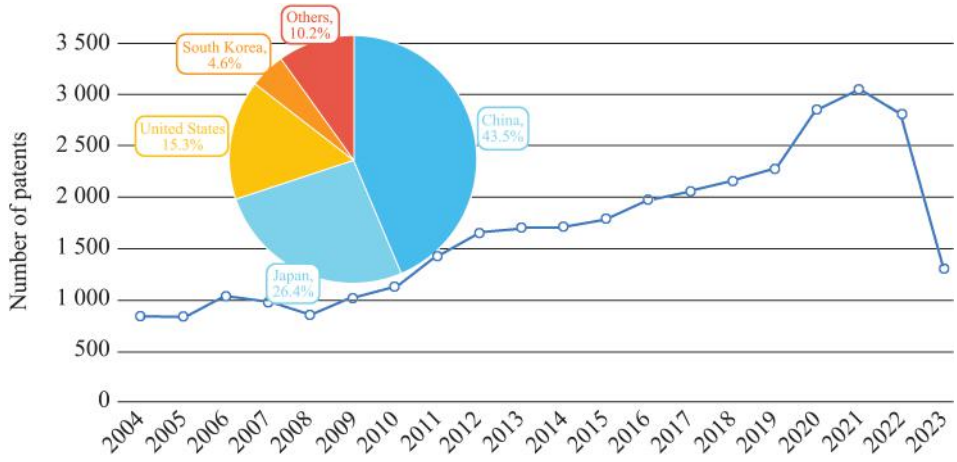

Figure 66 Global Trends in Patent Applications and Source Countries for Technology Related to Third-generation Semiconductors (Item)

(Source: PatSnap)

ii. Impact of Disruptive Technological Innovation

As the outstanding representatives of the third generation of power semiconductors, gallium nitride transistors and silicon carbide MOSFETs are attracting an increasing amount of attention from the industry and have many advantages compared with traditional silicon materials. The larger band gap and higher critical field strength of gallium nitride and silicon carbide materials mean that power semiconductors made from these two materials have superior properties such as high voltage resistance, low on-resistance and small parasitic parameters. When applied in switching power supplies, they have the advantages of low loss, high operating frequency and high reliability, greatly improving the efficiency, power density and reliability of switching power supplies.

1. Silicon Carbide

Some of the most significant characteristics of silicon carbide power devices include high voltage, high frequency, and low consumption, characteristics that maximize energy conversion efficiency. Thanks to technological breakthroughs and falling costs, silicon carbide power devices will become more widely used in different fields such as new energy electric vehicles and charging piles.

(1) The Global Market Size of Silicon Carbide Devices Is Growing at a Considerable Rate, with Europe, North America and the Asia-Pacific Region Being the Three Major Players in This Field

The development of electric vehicles has higher requirements for power electronics and power systems. They must be lighter, more compact, more efficient and more reliable. According to Yole, in 2022 the size of the global market for silicon carbide power devices was USD 1,472 million, an increase of 35.05% over the previous year. The expectation is that the size of the global market for silicon carbide power devices will exceed USD 1.9 billion in 2023.

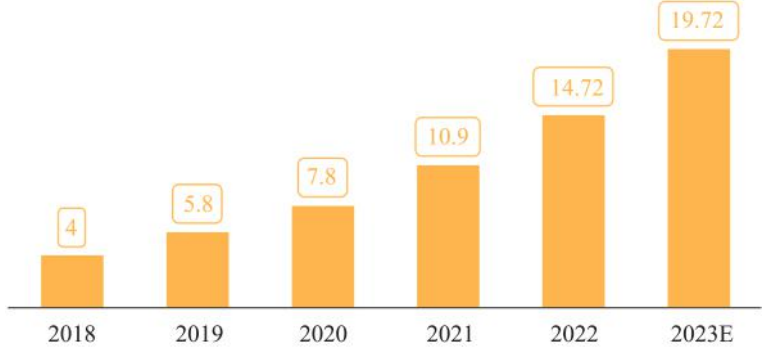

Figure 67 Prediction of the Size of the Market for Silicon Carbide Power Devices (In USD '00 Million)

(Source: Yole Intelligence)

In light of the continuous development of the silicon carbide industry, the market competition pattern of silicon carbide power devices is also changing. However, the market share of such products is still monopolized by global giants such as STMicroelectronics, Wolfspeed, ROHM, Infineon, Mitsubishi Electric, and Onsemi. These top six global companies hold 99% of the total market share, with STMicroelectronics accounting for a relatively large percentage of this total (over 40%). These companies are based in countries in Europe, North America, and the Asia-Pacific region, and have a combined market share of 12.5% for ROHM and Mitsubishi Electric in the Asia-Pacific region.

Table 8 Global Competition Pattern for Silicon Carbide Power Devices

Region	Company Name	Market Share
Europe	STMicroelectronics	41.4%
Europe	Infineon	22.8%
North America	Wolfspeed	15.2%
Asia	ROHM	9.9%
North America	Onsemi	5.1%
Asia	Mitsubishi Electric	2.6%

The figure shows the trend in patent applications in the global silicon carbide industry over the last two decades. This trend indicates that the number of patent applications in the field of global silicon carbides has grown rapidly on the whole. The past two decades can roughly be divided into two phases. The first phase was a period of rapid growth from 2008 to 2018, and the second was a period of even more rapid growth in patent applications from 2019 to the present.

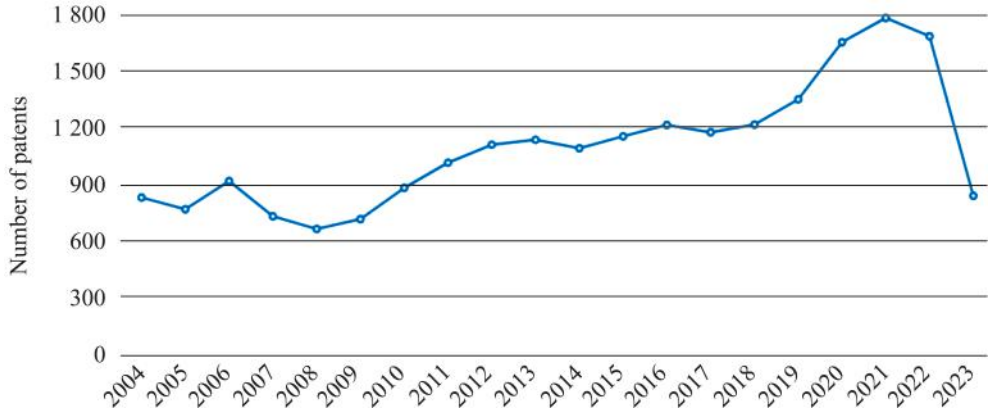

Figure 68 Global Trends in Patent Applications Related to Silicon Carbides (Item)

(Source: PatSnap)

(2) Technological Development Trends

Due to the hardness and high melting point of silicon carbide materials, the production process is much more difficult than it is for silicon-based materials. Moreover, because the crystal growth rate is slow and the production cycle of high-quality silicon carbide substrate is much longer than it is for traditional silicon, the resulting limited supply and high price of silicon carbide substrate have been one of the main factors impeding the large-scale application of silicon carbide devices. Silicon carbide substrates are usually synthesized from

high-purity carbon powder and silicon powder. Under a special temperature field, silicon carbide crystal ingots of different sizes are grown using a mature physical vapor transfer method, while silicon carbide substrate is produced through multiple processes. The core process is crystal growth and the core equipment is a crystal growth furnace. There are three key points to keep in mind when it comes to the future development of silicon carbide substrates. First, the process and equipment can be optimized to improve the growth rate, which includes improving growth techniques such as chemical vapor deposition and physical vapor deposition. Also, new forward-looking preparation technologies, such as electron beam lithography, ion implantation, and hydrogen annealing, are expected to improve the processing and performance of silicon carbide wafers. Second, losses and defects can be controlled to improve the yield. Thanks to lean growth and processing technology, the lattice defects of silicon carbide wafers can be reduced, improving electronic performance and reliability. Third, the wafer size can be expanded and the structure can be improved. Also, larger diameter wafers, heterogeneous structures, or multilayer wafers can be developed to provide more design flexibility and performance options.

2. Gallium Nitride

Gallium nitride has been applied to different types of telecom base stations thanks to its advantages like high power and high bandwidth. GaN-on-SiC devices are widely used in Remote Radio Head (RRH) base stations and massive 5G MIMO. Companies such as Huawei, Nokia, and Samsung adopt gallium nitride technology in their massive 5G MIMO facilities.

(1) Gallium Nitride Has Huge Market Potential, with the Asia-Pacific Region Holding a Leading Position in This Field

Gallium nitride has the highest electron saturation drift rate and is suitable for high-frequency application scenarios. Thanks to falling costs, gallium nitride is expected to replace diodes, IGBTs, MOSFETs and other silicon-based power devices in the field of low and medium power. In terms of voltage, silicon materials have an advantage at 0-300 V, silicon carbide has an advantage above 600 V, and gallium nitride materials have an advantage between 300 V and 600 V. According to Yole, gallium nitride has significant application potential in the low voltage market of 0-900 V, and it accounts for approximately 68% of the entire power market. Based on the overall market, which is worth USD 15.4 billion, the potential market for gallium nitride exceeds USD 10 billion. Yole Group's survey shows that the market value of RF gallium nitride devices was USD 1.3 billion in 2022 and is expected to reach USD 2.7 billion by 2028, with an annual compound growth rate of 12% during the period from 2022 to 2028.

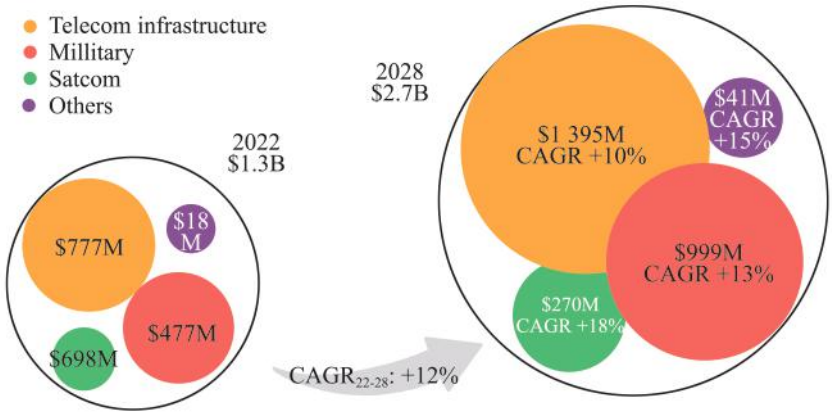

Figure 69 Size of Market for Gallium Nitride RF Devices for 2022 and Market Size Forecast for 2028

(Source: Yole group)

In terms of the patterns in the global market for gallium nitride substrate, Japanese manufacturers Sumitomo Electric, Mitsubishi Chemical, and Sumitomo Chemical occupy a leading position, holding a combined market share of over 85%. In terms of the market for gallium nitride devices, China's Innoscience had a market share of 16% in 2022, ranking third overall. It is clear that the Asia-Pacific region has prominent advantages in this field.

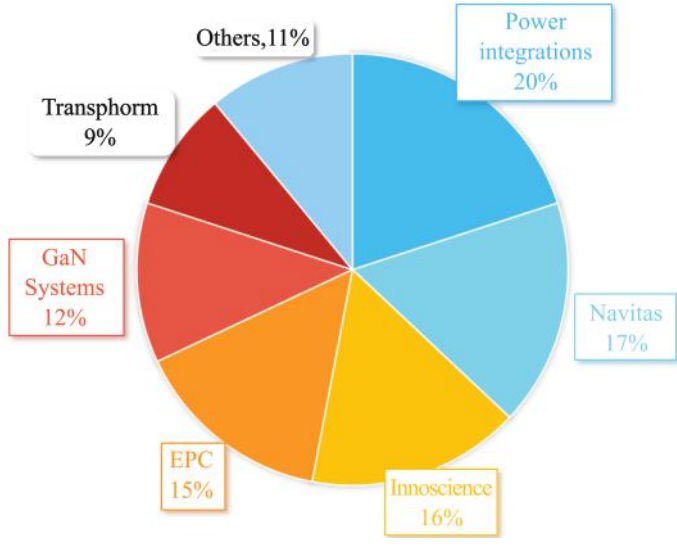

Figure 70 Market Shares of Global Gallium Nitride Power Device Suppliers in 2022

(Source: TrendForce)

The above figure shows global trends in patent applications related to gallium nitride. During the past two decades, technological innovation in the field of gallium nitride has advanced rapidly. In 2004, there were only around 300 patent applications, but by 2022 this

number had surged to over 900, representing a more than threefold increase. Evidently, the overall trend for patent applications in the field of gallium nitride is one of rapid growth. The distribution of technology source countries in the field of gallium nitride is shown in the figure above. As shown, China has the largest number of patent applications and accounts for approximately 50.1% of the global total, which is far more than any other country. Japan ranks second with 23.9% of this total, while South Korea ranks fourth with a 4.8% share. It can be seen that in the global field of gallium nitride, Asian countries represented by China, Japan and South Korea have strong technological competitiveness and innovation capabilities.

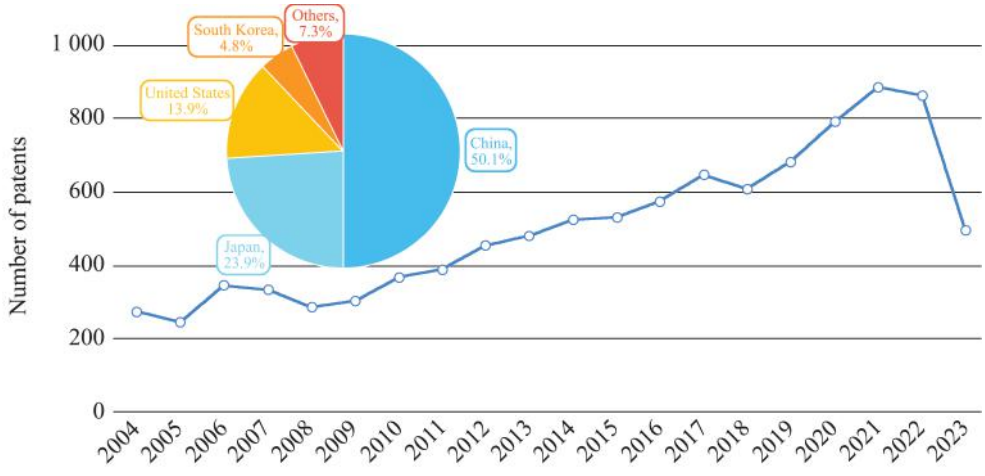

Figure 71 Global Trends in Patent Applications Related to Gallium Nitride and Technology Source Countries (Item)

(Source: PatSnap)

(2) Technological Development Trends

Although a lot of research has been carried out on gallium nitride materials, the following aspects are still the focus of future development so that gallium nitride materials and devices are more reliable and last for longer. The first of these aspects concerns the preparation and technology of p-type gallium nitride. P-type gallium nitride is more difficult to develop than n-type gallium nitride. Also, Mg-doped gallium nitride cannot show the nature of the acceptor because it is passivated by hydrogen atoms. Therefore, the direction of future development involves solving the preparation and process problems associated with p-type gallium nitride. The second aspect concerns the preparation and technology of AlGaN materials with high Al components. At present, it is still difficult to prepare AlGaN materials with high Al components, and this is especially true for materials with device structures. The reason for this is not only because the lattice mismatch in the traditional MOCVD growth method is large and various reaction processes are complex and difficult to control, but also because the material's energy gap is wider and the doping activation efficiency is lower.

Therefore, it is important that future development be directed toward further optimizing the preparation and process technology of AlGaN materials with high Al components①.

Ⅲ. New Display

The new display industry refers to the use of new technologies, materials and processes to produce display equipment with high precision, high brightness and high definition, including LCDs, OLEDs (organic light-emitting diodes), miniature projectors, and flexible displays. With the advent of the information age, the new display industry has developed rapidly and has become an important part of all electronic products.

ⅰ. Development Trends and Regional Competitiveness

1. The Scale of the New Display Industry Is Huge Globally, and China Has a High Market Share

The new display industry has characteristics such as a large investment scale, rapid technological progress, a wide radiation range, and high industrial agglomeration. It is an emerging industry with a global annual output value of over USD 100 billion. According to statistics, the value of the output of the global display industry in 2022 was approximately USD 198.5 billion, with the market size of display panels accounting for USD 146.2 billion of this total. It is expected that the size of the market for global display panels will reach USD 255.1 billion by 2027, with an annual compound growth rate of approximately 11.8% during the five years from 2023 to 2027②.

In recent years, China's new display industry has been developing and growing, forming a complete industrial system from the supply side to the application side. In 2022, the output value of China's display industry exceeded RMB 490 billion, accounting for 36% of the global total and continuing to rank first in the world. Of this total, the output value of display panels was over RMB 360 billion, accounting for 48% of the global market. The shipment area of display panels was 160 million square meters, accounting for 68.6% of the global market and also ranking first in the world, with an increase of 5 percentage points year on year③.

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① Ji Q., Wang Y. & Hu X., Progress of research on gallium nitride materials for aerospace. Materials Reports 2022, 36 (22).

② *White Paper on the Development of New Display Industry Technology* (2023).

③ Ministry of Industry and Information Technology: China's display industry continues to rank first in the world in terms of scale, https://cn.chinadaily.com.cn/a/202308/22/WS64e478a4a3109d7585e4a510.html.

2. With Advances in Technology, Global Patent Applications Related to the New Display Industry are Experiencing a Second Wave of Growth

Before 2010, the global new display industry experienced its first wave of development, with LCD as the mainstream technology. With continuous improvements in technology, the trend in global patent applications was initially one of growth, but then it started to show a decline. In recent years, technological innovation in the new display industry has accelerated. In 2013, Sony released its first 4K TV, marking the beginning of the ultra-high definition era for new displays. In recent years, technologies such as flexible displays, quantum dot displays, and laser displays have emerged, providing a new direction for the development of the new display industry. Meanwhile, the application field of new display technology continues to expand. Not only does this cover traditional consumer electronic products such as smartphones and TVs, but it has also gradually expanded to encompass vehicle displays, smart homes, medical care, education, and various other fields. Since 2010, patent applications in the global new display industry have experienced a second wave of explosive growth, with the number of patent applications surpassing 25,000 around 2020.

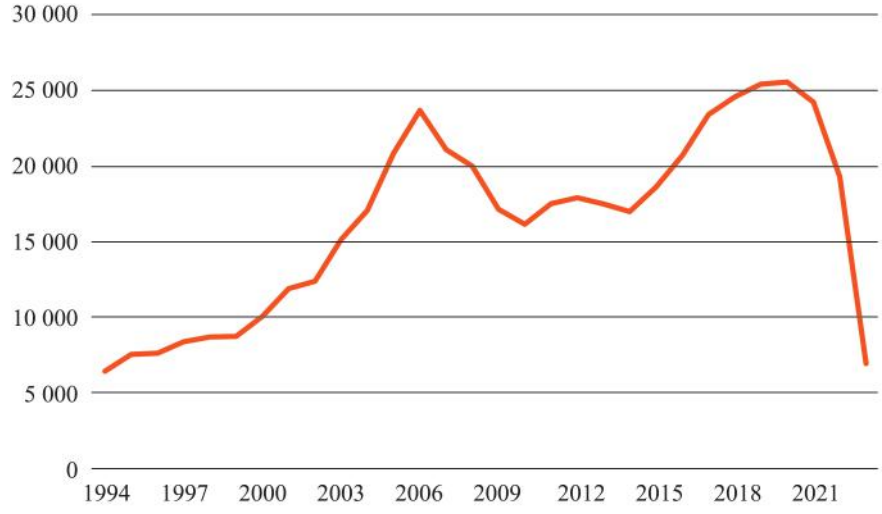

Figure 72 Global Trends in Patent Applications Related to the New Display Industry (Item)

(Source: PatSnap)

3. Innovation Is Active in East Asia, with Patent Applications in the Region Accounting for over 90% of the Global Total

The Asian region, and especially East Asia, has become the world's largest market for the new display industry in terms of both production and consumption. In recent years, the region has witnessed significant progress in the new display industry, with the emergence of new international display industry leaders such as Sharp, Epson, SONY, TCL, BOE, Hisense, LG, and Samsung. Japan, China, and South Korea rank among the top three in the world in terms of patent applications, accounting for 92% of the global total. Of these

countries, China has made the most significant progress in fields such as ultra-thin, flexible, transparent displays and 4K/8K ultra-high-definition displays, and has successively launched a number of global debut products, constantly leading global trends.

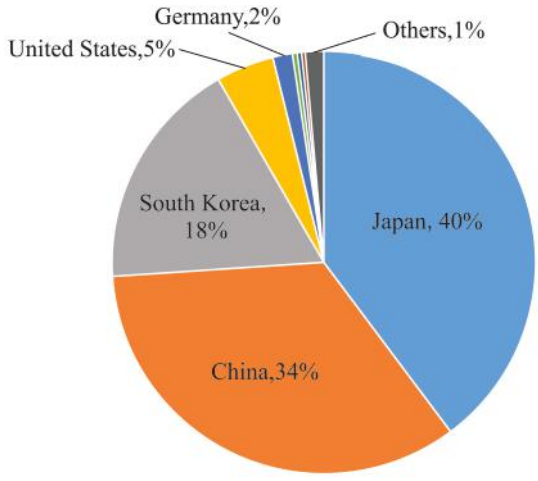

Figure 73 Sources of Global New Display Industry Technologies

(Source: PatSnap)

ii. Impact of Disruptive Technological Innovation

1. Micro-LED

Micro-LED technology is a type of LED plane display technology with high pixel density assembled on the TFT or CMOS backplane according to the micron cycle with micron-scale LED as the pixel. The display principle involves designing LED structures with thin film, micro, and array characteristics, with its size ranging from just a few microns to tens of microns. After this, a large number of micro-LED light-emitting chips are transferred to the TFT or CMOS backplane, the micro-LED chip array is arranged in cycles, and each pixel is controlled and individually driven to light up. Micro-LED displays have advantages such as high luminous efficiency, high brightness, short response time and good reliability.

In recent years, micro-LED has been favored by many downstream panel manufacturers thanks to its excellent display performance, and has developed in a way that is oriented towards small display products such as commercial large-scale display products and multifunctional head-worn and wearable devices. According to the Gaogong Industry Institute, given gradual technological development and falling costs, the size of the global micro-LED market is expected to reach USD 3.5 billion in 2025 and USD 10 billion in 2027①.

① https://mp.weixin.qq.com/s/pEqXHarJxGzjV1xzES2iOg

（1）The United States, China, Japan and South Korea Have Become the Main Technology Sources in the Micro-LED Field

The United States currently has the most advanced micro-LED display technology of any country in the world. In 2006, the University of Illinois in the United States transferred the early results of its research in micro-transfer printing（μTP）technology to the then start-up Semprius. This technology was later obtained by X-Celeprint, a wholly-owned subsidiary of XTRIONN. V, and as of now the batch printing transfer of wafer-level devices with one-micron precision has been realized. The Chinese Mainland has kept up with the pace of international research and development, and leading enterprises and universities have stepped up research and development in forward-looking Micro-LED technologies. Of these, TCL China Star Optoelectronics, XGL Optoelectronics and San'an Optoelectronics have started to develop Micro-LED epitaxial chips, and have also achieved a 15-micron miniaturization process. San'an Optoelectronics has made Micro-LED a focus of its future development. Large companies in Japan and South Korea have also carried out a lot of scientific research and production in an attempt to seize the micro-LED market.

（2）Global Patent Applications Related to Micro-LED Are Showing a Steady Upward Trend

In 2000, the United States successfully prepared a 10 × 10 blue micro-LED array, laying the theoretical foundation for the development of micro-LED displays. Micro-LED display technology has developed rapidly in recent years thanks to continuously progressing technology and improvements in the industrial chain. Since 2010, there has been a worldwide surge in research enthusiasm for micro-LED display technology, and the number of patent applications has increased year by year from 834 in 2010 to 3, 505 in 2020.

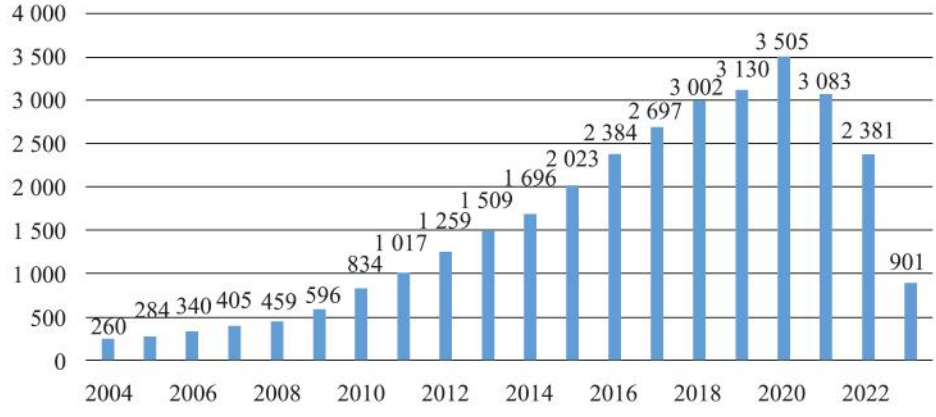

Figure 74　Trends in Global Patent Applications Related to Micro-LEDs

（Source: PatSnap）

（3）Technological Development Trends

Although micro-LED technology has developed rapidly in recent years, it is still in the

early stages of development, which means that the time is not yet right for its large-scale production and application. Therefore, to ensure the further development of micro-LED it is important that the core technical problems be solved. The four major development trends are as follows.

Micro-LED chip technology: This mainly includes size, pixel arrangement, and LED color conversion. 1) In terms of size, the size of micro-LED chips is currently being miniaturized further. This trend requires synchronous support of the process and equipment. In addition, in order to solve problems such as the cutting and edge effects caused by chip miniaturization, micro-LEDs will no longer have any substrate in the future. 2) In terms of pixel arrangement, the current mainstream technology involves horizontal arrangement and vertical stacking. 3) In terms of LED color conversion technology, quantum dot color conversion technology is considered one of the candidate technical routes that might be able to solve the problems that micro-LED displays are currently facing, such as low light efficiency and the mass transfer of red LEDs.

Packaging technology: COB/COG technology has gotten the attention of LED display manufacturers in recent years, but the technology has relatively strict requirements for transfer yield and module substrate accuracy. Currently, there is still room for improvement in terms of yield, consistency, and mass production. MiP/IMD avoids the strict requirements of COB/COG while also solving problems such as mixed light, which is the mainstream path for packaging and applications for current micro-LEDs.

Mass transfer: Non-contact (mainly laser transfer) is currently an important aspect of research for mass transfers. This is in line with the future trend of non-substrate micro-LED mass transfers.

Drive and control: PM drive mode has developed rapidly in recent years. This technology enables micro-LEDs to have characteristics such as high levels of integration, ultra-low power consumption, an ultra-high refresh rate, and a gradually improving cost performance. However, the PM driver chip mainly operates in PWM scanning mode, which suffers from flickering and various other problems and is limited in certain application fields. AM drivers have more potential in theory, but in large-size micro-LEDs AM drivers also face problems such as high costs and insufficient industry maturity. This means that further development and optimization are needed. In micro-sized micro-LEDs, silicon-based CMOS AM drivers have become the mainstream drivers.

2. Naked-eye 3D Displays

Since people can obtain impact stereoscopic visual effects through naked-eye 3D display without wearing any auxiliary equipment, naked-eye 3D displays are an inevitable development trend of FPD technology and are considered to be the most vibrant next-generation display technology. They can be widely used in home entertainment, media advertising, exhibitions, scientific research and education, and various other fields.

According to the Shangpu Group, in 2022 the number of naked-eye 3D display shipments reached 35 million units globally, and the market size reached USD 10.4 billion. It is expected that the number of naked-eye 3D display shipments will reach 140 million units globally in 2027, with the market size reaching USD 44 billion. In addition, it is expected that from 2023 to 2027, the compound growth rate of global naked-eye 3D display shipments and market size will be 28.6% and 29.5% respectively①.

(1) Enterprises in the Asia-Pacific Region Have Penetrated the Entire Industrial Chain, Showing Strong Competitive Strength

The global naked-eye 3D industry mainly comprises the following types of enterprises:

Display manufacturers: These are mainly large LCD manufacturers such as Samsung, LG, and Sharp, as well as Chinese LCD manufacturers such as BOE and TCL CSOT. These companies mainly obtain the naked-eye 3D effect by adding a grating layer or lens layer to the surface of the display screen and applying it to terminal products such as televisions, laptops, and tablets.

Naked-eye 3D solution providers: These are mainly Chinese naked-eye 3D solution providers such as KDX, TCL, and Shenzhen Konka, as well as non-Chinese naked-eye 3D solution providers such as SuperD and EVIS. These companies mainly provide naked-eye 3D solutions that integrate software algorithms, hardware modules, and content production to help display manufacturers or terminal product manufacturers obtain naked-eye 3D effects.

Naked-eye 3D content producers: These are mainly Chinese naked-eye 3D content producers such as Wanwei Cloud Vision, eViewTek, and 3D Vision Display, as well as non-Chinese naked-eye 3D content producers such as RealD and MasterImage 3D. These companies meet consumers' demand for a naked-eye 3D experience, mainly by providing content such as 3D movies, games, and animations.

(2) Patent Applications in the Naked-eye 3D Display Industry Have Experienced a Second Wave of Growth in Recent Years

The naked-eye 3D display industry got a late start. In 2010, naked-eye 3D technology began attracting widespread attention, sparking a wave of naked-eye 3D display technology in the industry. At that time, many manufacturers including Sharp, HTC, LG, Konka, Hisense, and Toshiba launched products equipped with naked-eye 3D display technology on PCs, mobile phones and TVs, resulting in a surge in the number of global patent applications. However, due to insufficiently mature naked-eye 3D display technology, these products were not received warmly in the market. As for trends in patent applications, in 2016 the number of patent applications in the global naked-eye 3D display industry peaked for the first time and subsequently began to decline. In recent years, thanks to technological breakthroughs, the development of pupil tracking technology, and the boost provided by

① https://baijiahao.baidu.com/s?id=1768688905129035762&wfr=spider&for=pc

emerging technologies such as the meta-universe, global naked-eye 3D display technology has risen for a second time, with huge potential for future development.

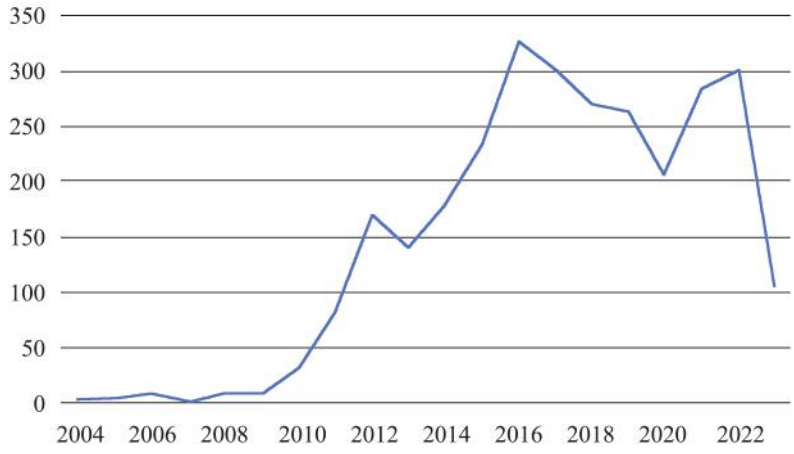

Figure 75 Trends in Patent Applications Related to the Naked-eye 3D Display Industry

(Source: PatSnap)

(3) Technological Development Trends

As display technology continues to become more advanced, naked-eye 3D technology is also constantly being optimized and innovated to improve performance metrics such as resolution, viewing angle, viewing distance, and color reproduction while simultaneously reducing costs and power consumption as well as improving reliability and compatibility. For example, micro-LED and laser light sources are being utilized to obtain naked-eye 3D displays with higher brightness and contrast. Also, artificial intelligence and deep learning are being utilized to achieve more efficient and accurate naked-eye 3D image processing and generation, while holographic imaging and light field display are being utilized to obtain more realistic and natural naked-eye 3D effects. Its applications might also gradually expand to more fields such as medical care, education, and tourism. Naked-eye 3D display technology can also be combined with other technologies like VR and AR to form more applications and experience effects①.

① https://mp.weixin.qq.com/s/b2c-OCoeoFnFSimXJH8Jug

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