Strategic High-Tech Development Trends Post-print

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Abstract

[Objective/Significance] Strategic high technologies constitute critical drivers of national economic and social development, representing a comprehensive manifestation of a country' s scientific and technological innovation capacity. Identifying developmental directions for strategic high technologies, and fostering and developing strategic emerging industries, are of paramount significance for stimulating the new economy, strengthening new growth drivers, and capturing commanding heights. [Method/Process] Building upon the strategic research for the 2050 Science and Technology Development Roadmap organized by the Chinese Academy of Sciences, this study employs a combined methodology of expert evaluation and literature intelligence analysis. Ten strategic high-tech domains were selected, including information technology, biology and medicine, new materials, advanced manufacturing, advanced energy, ecological environment, space, marine science, modern agriculture, and resources. Over 100 experts were convened to conduct developmental trend research, and the resulting report was extensively reviewed through expert symposiums. [Result/Conclusion] This paper elucidates the overall trends in global strategic high-tech development and the developmental trajectories within the ten aforementioned domains.

Full Text

Preamble

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Abstract

[**Purpose/Significance**] Strategic high technology represents a crucial driving force for national economic and social development and embodies a country' s comprehensive scientific and technological innovation capabilities. Identifying development directions in strategic high technology and fostering emerging industries of strategic importance are vital for promoting the new economy, strengthening new growth drivers, and seizing the commanding heights in international competition.

[**Method/Process**] Building upon the Chinese Academy of Sciences' "Science & Technology Roadmap to 2050" strategic research, this study employed a combination of expert judgment and literature analysis. Over 100 experts were organized to conduct development trend research across ten strategic high technology domains: information technology; biology and medicine; new materials; advanced manufacturing; advanced energy; ecological environment; space; marine; modern agriculture; and resources. The resulting research report was further refined through extensive expert seminars.

[**Result/Conclusion**] This paper elucidates the overall global trends in strategic high technology development and examines trends within each of the ten priority domains mentioned above.

Keywords: strategic high technology; global development trends; science and technology development roadmap; 13th Five-Year Plan

Strategic high technology serves as a major driver of national economic and social development and represents the comprehensive embodiment of national scientific and technological innovation capabilities. Mastering strategic high technology in critical domains means mastering the initiative. Identifying development directions in strategic high technology, making forward-looking deployments, and cultivating emerging industries of strategic importance are essential for fostering new economic growth, strengthening new momentum, and capturing strategic high ground.

1 Global Trends in Strategic High Technology Development

A new round of global scientific and technological revolution is gestating and rising, with industrial transformation in the ascendant. Strategic high technologies are deeply integrating and widely penetrating all aspects of human society. Strong demand from economic and social development has created fresh growth space for strategic high technology, making innovation more active and allowing the energy for transformative breakthroughs to accumulate continuously. The global innovation landscape is accelerating its reconstruction, with strategic high technology becoming the focal point of comprehensive national power competition, presenting new development trends and characteristics.

1.1 Multidisciplinary Convergence and Integration

Emerging disciplines and frontier fields continue to generate new breakthroughs, giving rise to new forms and models of high-tech industries and achieving integrated connectivity from basic research to applications. For example, the combination of brain science with mathematics, information science, and other disciplines is catalyzing brain-computer interface technology, which will greatly advance artificial intelligence and complex network technologies while promoting the prevention and treatment of mental illnesses and neurodegenerative diseases. Applications such as personalized custom-made bones and cardiac membranes have emerged successively. In new materials, continuous integration with information technology and advanced manufacturing technology is driving innovations in metallic materials, semiconductor materials, advanced energy storage materials, and biomedical materials, strongly supporting the development of related application fields and even creating new application domains.

1.2 Development Toward Green, Intelligent, and Service-Oriented Directions

Strong demand from economic and social development, coupled with continuously upgrading and diversifying consumer needs, has greatly expanded the demand space for strategic high technology. Whether it is the daily-life demand for upgraded information services such as e-commerce and location-based services, or global challenges like climate change, population aging, and resource-energy security, all urgently require strategic high technology to develop toward green, intelligent, and service-oriented directions. Future science and technology will place greater emphasis on ecological environmental protection and restoration, dedicated to developing low-energy-consumption, high-efficiency green technologies and products. Green agriculture, focusing on molecular module design breeding, accelerated photosynthesis, and smart technology R&D and applications, will create new agricultural biological varieties, improve agricultural product yield and quality, and ensure food and safety security. The human-machine integrated intelligent manufacturing model and 4D printing technology combining smart materials with 3D printing will drive industrial production from large-scale centralized manufacturing to customized distributed production, leading the “digitization of the physical world”and the “intelligentization of the material world.” High-tech industries are developing at an astonishing pace; for instance, the global big data technology and services market has achieved a compound annual growth rate of 39% over the past five years.

1.3 Increasing Role in Supporting National and Social Development

Disruptive technologies continue to emerge, catalyzing major industrial transformations. The replacement of conventional technology by high technology and labor-intensive technology by intelligent technology is becoming the mainstream trend. Emerging technologies such as cloud computing and the Internet of Things provide the foundation for large-scale data production, sharing, and

application, continuously penetrating economic, social, and public management domains. The "Internet Plus" initiative is flourishing, triggering endless business model innovations and leading to revolutionary transformations in development approaches across various fields, fundamentally changing human production and life. Defense science and technology innovation is accelerating, with military-civilian integration developing in depth across all elements, multiple domains, and with high efficiency, which will lead to the development of more high-performance, low-cost, intelligent, miniaturized, and resilient weapons and equipment, unprecedentedly enhancing defense science and technology capabilities.

1.4 Countries Releasing New Strategies to Seize Opportunities

Major countries worldwide continue to increase investment in science and technology and have successively implemented major reform measures such as reorganizing national scientific and technological forces and optimizing research layouts to seek opportunities for economic recovery and sustainable development. For example, despite federal budget cuts, the United States has continued to increase R&D investment, focusing on clean energy, advanced manufacturing, aerospace, brain science, network and information technology, nanomaterials, climate change, and major scientific and technological infrastructure. The European Union launched the €70 billion "Horizon 2020" program in 2014, focusing on key technologies such as communications, nanotechnology, new materials, advanced manufacturing, biotechnology, and aerospace, as well as societal challenges including climate change, renewable energy, food security, and aging populations.

1.5 International Cooperation Playing an Increasingly Important Role

International scientific and technological cooperation, focusing on global common challenges, is developing toward higher levels and broader scopes. The complexity and risk of common challenges facing humanity, along with the arduousness and high costs of scientific research, will greatly promote collaborative research and resource sharing, driving high-level scientific and technological cooperation to be carried out extensively and deeply, increasingly rising to the national and regional levels or even becoming global joint actions. For example, after the completion of the main construction of the International Space Station in 2011 and its transition to full application, all major participating countries have tightly deployed more scientific and applied research and developed more advanced scientific payloads for the International Space Station. The International Space Station will operate at least until 2024 and is expected to conduct thousands of scientific experiments, observations, space applications, and technology tests.

2.1 Information Technology Domain

Information technology undergoes a major transformation every 10 to 15 years, spawning new markets, business models, and industries. Prominent technological development trends include: the Internet of Everything composed of human-machine-thing connectivity becoming a trend; basic software and hardware technologies 孕育着革命性突破 (nurturing revolutionary breakthroughs); big data catalyzing data-intensive knowledge discovery, which will generate enormous impetus for government governance and socio-economic development; Moore' s Law becoming difficult to sustain; information infrastructure devices standing at the eve of major transformation; and new-principle devices such as memristors, spintronic devices, and quantum devices potentially achieving major breakthroughs.

2.2 Biotechnology and Medicine Domain

Biotechnology and medicine have entered a multi-domain convergence paradigm, with engineers, physicists, biologists, and clinicians jointly participating in solving major problems and challenges. Research approaches are developing toward a combination of precise "individual" detection and massive systematic samples. Technologies for regulating and reconstructing biological complex systems and life complex processes are brewing major breakthroughs. The global bio-economy is having a major impact, with the bio-economy and bio-industry becoming priorities in national planning and layout for many countries. Developed and newly industrialized countries have begun to attach importance to the preservation, mining, and utilization of biological big data. As emerging biotechnologies move toward application, how to develop safely and rationally has become an urgent problem to solve. Simultaneously, in the process of biotechnology moving to market, intellectual property protection and development have become the most important influencing factors.

2.3 New Materials Technology Domain

Whether in aviation, aerospace, informatization, or deep-sea resource and mineral exploration and development, all pose newer and higher requirements for materials, continuously pursuing higher material service performance. New materials are rapidly developing toward personalization, compositization, and multifunctionalization, with new processing methods such as 3D printing receiving significant attention. New materials technology places greater emphasis on shortening R&D cycles and reducing R&D costs, with new materials R&D shifting from an "experience-guided experimentation" model to a new "theoretical prediction-experimental validation"model. New materials technology also places greater emphasis on solving energy and resource shortages and promoting sustainable development, with green environmental protection and energy saving and emission reduction becoming common goals.

2.4 Advanced Manufacturing Technology Domain

Intelligent manufacturing, as a product of the integration of new-generation information and communication technology (ICT) and manufacturing technology, represents the main direction of advanced manufacturing technology development. Digital factories have become a hotspot in international advanced manufacturing research, with one goal of Germany's Industry 4.0 being the realization of digital factories. Secure industrial control systems are one of the key technologies determining the success of intelligent manufacturing, with all countries attaching great importance to research on industrial control system security and assurance technology. Robotics technology is becoming a cross-integration entity of frontier technologies, approaching an era of explosive innovation. Various economic and technological powers have successively formulated robotics development strategic plans, striving to achieve leadership in next-generation robotics in the next 10 to 20 years.

2.5 Advanced Energy Technology Domain

World energy development has entered a new round of strategic and structural adjustment, with many countries formulating energy science and technology development roadmaps. The efficient and clean utilization of fossil energy will be vigorously developed. New geophysical exploration technologies are maturing, and fossil energy extraction technologies continue to improve. Renewable and new energy technologies continue to achieve breakthroughs: solar photovoltaics are expected to achieve grid parity; wind turbines are developing toward large-scale, specialization, and high efficiency; biomass energy applications are developing toward multi-feedstock and multi-purpose directions; solar thermal utilization and deep geothermal energy may become major renewable energy sources; and new nuclear power systems represent the hope for humanity to fundamentally solve energy problems. Hydrogen fuel cell vehicles will soon enter the market introduction phase. Power transmission and distribution are placing greater emphasis on safety, efficiency, and large-scale integration of renewable energy, with future power grids expected to achieve a major transformation from AC to DC.

2.6 Ecological and Environmental Technology Domain

The world' s major developed and developing countries are accelerating their layout to seize strategic high ground in ecological and environmental technology. New high-tech R&D and downstream industrial clusters are emerging intensively. In the next 5 to 10 years, breakthroughs are expected in areas such as ecological and environmental security assurance, water and soil safety, clean production and circular economy, climate change response, and environmental health. There is increased attention to natural and anthropogenic ecological environmental changes and their regulation, with particular emphasis on integration between science and technology and interdisciplinary collaboration, focusing on building a full-chain system from basic applications to high-tech

R&D. Original innovation is receiving increasing attention, with the cycle of scientific and technological innovation, achievement transformation, and technology updating being shortened.

2.7 Space Technology Domain

Space science exploration and research are expanding toward deeper, broader, and more refined directions, further deepening understanding of fundamental physical processes in the universe, understanding the physical nature of dark matter and dark energy, revealing the physical causes of solar magnetic fields, solar flares, and coronal mass ejections and their interactions, and exploring extraterrestrial life and the survival performance and capabilities of Earth life in extraterrestrial space. Breakthrough progress in unmanned aerospace vehicles will trigger profound changes in aerospace paradigms. Integrated application research of aerospace information and effective satellite monitoring and maintenance have become key to development. Research, construction, and development of space-time reference technology have become focal points of attention. Space exploration big data has placed higher demands on ground-based receiving facilities. Research in space applications has entered an era of big data characterized by globalization, systematization, quantification, and informatization.

2.8 Marine Technology Domain

Contemporary marine technology is expanding from coastal to open ocean areas and from shallow to deep waters. Sea-air integration and multi-platform, multi-perspective acquisition of marine environmental information, providing global or regional real-time basic information and information product services through network systems, represent the development trend of marine monitoring technology. Underwater vehicles have become the most important platforms for exploration and operation, developing toward practical application and integrated technical systematization. Marine oil and gas exploration is advancing to deep waters, continuously developing new platforms suitable for deepwater oil and gas development, multi-functional floating production facilities, and underwater production systems. Natural gas hydrates have become a hot spot in new energy R&D, with exploration and identification, fidelity sampling technology, development, and environmental effects becoming priorities. Marine biological resource protection, evaluation, and exploitation have become focal points of international competition, with innovation in marine biological resource intensive processing and new drug creation flourishing. Deep-sea mineral resource exploration technology is developing toward greater depth and near-seafloor directions. Seawater comprehensive utilization technology is developing toward systematization, integration, and comprehensiveness. Marine energy technology is developing toward large-scale, low-cost, high-efficiency, high-reliability, and commercialization directions.

2.9 Modern Agriculture Technology Domain

Future agricultural science and technology will focus on productivity improvement, resource-efficient utilization, and sustainable development. Several key areas are showing new characteristics: international biotechnology breeding demonstrates multidisciplinary cross-integration and high-level integration, with the construction of design breeding systems leading leapfrog development in animal and plant breeding, while the modern seed industry shows a globalization and monopolization trend in technology and markets. Conservation-oriented agriculture focuses on improving comprehensive resource utilization efficiency, with soil science and technology developing from single disciplines toward interdisciplinary integration and research methods shifting from traditional techniques to modern high-tech applications. Fertilizer science and technology, based on meeting crop needs for high yield, quality, and efficiency, focuses on developing slow/controlled-release and environmentally friendly new fertilizers. Efficient water-saving technology, building upon traditional water-saving techniques, is developing toward quantification, standardization, patterning, and integration. Precision agriculture, marked by intensification, mechanization, and informatization, is developing toward higher levels. Smart agriculture, centered on green precision and supported by modern sensing, internet, IoT, cloud computing, and big data technologies, has become an inevitable future trend.

2.10 Resources Technology Domain

Understanding of metallogenic regularities in important metallogenic belts will become more profound, with metallogenic model research developing from constructing individual deposit models to constructing regional deposit models. Prospecting prediction research is developing toward covered areas and deep Earth, with "deep exploration and blind target searching" becoming the new direction for future prospecting prediction. Rare metals are considered next-generation strategic mineral resources, and their development has become a hot spot, with Western developed countries proposing new strategies one after another. Mineral resource surveys and research in marine and polar regions have received high attention from countries worldwide, especially developed nations. Oil and gas exploration and development research shows trends of multidisciplinary integration and technological convergence, with wide application of high-precision analytical testing technology, seismic exploration technology, and advanced drilling technology improving oil and gas exploration success rates and development efficiency. Unconventional oil and gas resource exploration and development technology and equipment will be further developed, with deep, deepwater, and polar region oil and gas exploration and development technology being strengthened. Economically and environmentally friendly oil and gas resource exploration and development technology will receive greater attention.

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Note: Figure translations are in progress. See original paper for figures.