Global Strategic Development Trends in Nuclear Fusion and Their Implications

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Abstract

In the context of carbon-neutral energy transition, controlled nuclear fusion has become a key component of the future energy system. The United States, United Kingdom, Germany, Japan, and other countries are reviewing and formulating appropriate development strategies and technical routes, leveraging government funding to drive private capital investment, and integrating domestic advantageous forces and resources to promote collaborative breakthroughs, thereby seizing the technological high ground in nuclear fusion and accelerating the commercialization process. From the perspective of technological and industrial development, theoretical experiments and application explorations continue to achieve new breakthroughs, while additive manufacturing, AI, and other technologies are accelerating breakthroughs in technical bottlenecks, and market size continues to expand. Based on China's actual circumstances, it is recommended to further optimize China's nuclear fusion policy deployment across five dimensions: strategic planning, R&D support, industrial system, talent pool, and international cooperation.

Full Text

Preamble

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Research on Global Strategic Development Trends and Implications for Nuclear Fusion

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Abstract

[**Background**] In the context of carbon-neutral energy transformation, controllable nuclear fusion has become a key component of future energy systems. The United States, United Kingdom, Germany, Japan, and other nations have examined and formulated appropriate development strategies and technical roadmaps, leveraging government funding to drive private capital investment and integrating domestic strengths and resources to promote collaborative breakthroughs, thereby seizing the technological high ground in nuclear fusion and accelerating commercialization.

[**Purpose**] This study systematically reviews the latest strategic layouts for nuclear fusion in major countries, along with global technological progress and industrial trends, compares and analyzes China's current situation and shortcomings, and proposes relevant countermeasures and suggestions.

[**Methods**] Using literature research and policy text analysis, this paper summarizes trends in major national strategic layouts and technological development.

[**Results**] Major countries have formulated independent fusion strategies, driven private capital investment through government funds, and integrated national strengths and resources to promote collaborative R&D, thereby seizing the commanding heights of nuclear fusion technology and accelerating commercialization. From the perspective of technological and industrial development, new breakthroughs have been achieved in theoretical experiments and application exploration, additive manufacturing and AI are accelerating the resolution of technical bottlenecks, and market size continues to expand.

[**Conclusions**] China should maintain strategic resolve, fully consider the disruptive potential and risks of these technologies, actively yet prudently promote nuclear fusion research and industrial development, strengthen strategic planning, increase R&D support, improve the fusion industrial system, strengthen talent team building, and promote international scientific and technological cooperation.

Keywords: Controllable Nuclear Fusion, Strategic Planning, Industrial Path, Independent Innovation

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Controllable nuclear fusion is regarded as the "ultimate solution" to humanity's energy needs. Due to its clean, efficient, and self-sustaining safety characteristics, once commercialized, it could disrupt the energy landscape and reshape the geopolitical energy map [1]. In recent years, amid intertwined factors such as volatile energy markets, climate action, and geopolitical competition, contradictions between energy demand, security, and climate concerns have become increasingly prominent. Ensuring energy security and transformation has become a strategic priority for nations, and global attention to and investment in nuclear fusion technology research and development have grown accordingly.

Currently, global fusion research is shifting from a focus on international cooperation to intensified national competition. As carbon neutrality actions accelerated after 2020, major countries including the United States, United Kingdom, Germany, and Japan have formulated fusion development strategies [2], mobilizing government, industry, academia, and research institutions to seize the commanding heights of science, technology, and industry. With strong policy support, breakthrough achievements in fusion theoretical research and operational experiments continue to emerge, new technologies and materials are advancing, private enterprises are joining the race, and capital markets are developing rapidly. This paper employs literature research and policy text analysis to systematically review the latest strategic layouts of major countries and global technological and industrial trends, compare and analyze China's current situation and shortcomings, and propose relevant countermeasures and suggestions.

1 Global Nuclear Fusion Strategic Policy Trends

The United States, United Kingdom, Germany, Japan, and other major countries are strengthening their independent fusion development strategic layouts based on their respective technological and industrial foundations, further clarifying roadmaps for industrial development.

1.1 United States: Comprehensive Commercial Path Planning to Ensure Global Leadership

The United States is a powerhouse in fusion science research. With rapid growth in public and capital investment, the U.S. has deployed comprehensive nuclear fusion support policies to accelerate commercial application and large-scale deployment, ensuring its leadership in the new phase of the global fusion race.

First, the U.S. has clarified its strategic direction. In December 2020, the Department of Energy (DOE) released its first long-term strategic roadmap, proposing priorities for fusion research over the coming decades, including establishing prototype power plant infrastructure before 2040. In March 2022, the U.S. held its first White House Summit on fusion energy [3], establishing the overall framework of a "Bold Decadal Vision for Commercial Fusion Energy" and launching a DOE-wide initiative to commercialize fusion energy. This initiative emphasizes making full use of existing government resources to address scientific challenges for pilot plants, with the expectation of operating a commercially meaningful fusion pilot plant in the 2030s. In November 2022, the U.S. further listed nuclear fusion as one of five urgently needed disruptive technologies in its *Innovating to Achieve 2050 Climate Goals*.

Second, the U.S. has planned commercialization pathways and built a fusion innovation ecosystem. In June 2024, the DOE released the *2024 Strategic Plan for Fusion Energy* [4], strengthening consensus between the scientific community and industry, and promoting collaboration among government, private sectors, and international partners to address technology-application gaps and accelerate large-scale deployment and commercial application. This strategy focuses on actual industrial needs, formulating multiple initiatives to promote close cooperation between government and private sectors, including: providing $180 million for the Fusion Innovation Research Engine (FIRE) partnership; developing a fusion science and technology roadmap and releasing a "New Vision for Science" to guide the Fusion Energy Sciences (FES) program and inform DOE research, development, and demonstration investments; and establishing a public-private consortium framework to attract private investment and various social capital funds.

Third, the U.S. continues to increase funding to support collaborative breakthroughs by private sectors. Supported by the CHIPS and Science Act, in September 2022, the U.S. launched the "Milestone Program," providing $45 million to fund eight companies for pilot plant verification research. The fiscal year 2024 budget provided a record-high $1 billion in support. Statistics show that from 2020 to 2023, the U.S. launched dozens of fusion research projects, funding spherical tokamak devices, stellarator devices, plasma-related research, and technologies such as AI and deep learning. In 2024, the U.S. annual R&D budget for fusion science exceeded RMB 7.3 billion, with commercialization R&D funding exceeding RMB 6.1 billion, and established the Inertial Fusion Accelerated Research Program to continue supporting the NIF ignition facility.

Fourth, the U.S. is leading the globalization of fusion research. In 2023, during the COP28 climate conference, the U.S. launched an international fusion cooperation program, allied with partners to establish standard and regulatory frameworks, and jointly solve technical challenges. In December 2023, the White House Office of Science and Technology Policy released the *International Partnerships in a New Era of Fusion Energy Development* [5], proposing five measures: open research, marketization, regulatory frameworks, scientific talent, and public engagement.

1.2 United Kingdom: Building a Fusion Industrial Powerhouse and Promoting Advantageous Technology Exports

The UK leverages its strong foundation in fusion science and engineering, ensures stable policy and funding support, and aims to build a fusion industrial superpower to guarantee national energy security.

First, the UK has formulated a long-term development strategy. In October 2021, the UK released *Towards Fusion Energy: The UK Fusion Strategy* [6], proposing to achieve demonstration grid connection of fusion power before 2040, and completed site selection for the Spherical Tokamak for Energy Production (STEP) prototype power plant in October 2022. This strategy sets two major goals: commercial viability verification and technology export, focusing on shaping global leadership in international cooperation, science and technology, and commercialization.

Second, the UK has increased research funding. In November 2022, the UK provided £126 million to support the Fusion Industry Program and the Joint European Torus [7]. In September 2023, the UK announced an additional £650 million investment in fusion energy before 2027 [8] to support construction of new facilities to enhance fusion fuel cycle capabilities, advance the STEP program, develop new fusion science and human resources, and promote international collaborative projects.

Third, the UK is accelerating the improvement of its fusion regulatory system. In October 2021, the UK released the *Fusion Regulatory Framework* [9], proposing a systematic approach to fusion regulation to accelerate commercial development on the basis of technical safety.

1.3 Germany: Simultaneously Supporting Two Routes to Underpin Future Energy Systems

Although Germany has long established a policy of complete nuclear phase-out, challenges from climate change, energy demand, and energy security have become increasingly severe. The German government has established a "renewable energy—green hydrogen—nuclear fusion" energy strategy, positioning fusion as key to future energy systems.

First, Germany has organized expert systematic evaluation and simultaneously advanced magnetic confinement and laser inertial fusion research. In December 2022, the Federal Ministry of Education and Research (BMBF) established a Laser Fusion Expert Committee to analyze global laser fusion development trends and Germany's status and potential. In May 2023, the committee submitted the *Memorandum on Inertial Fusion Energy (IFE)* to government departments, systematically outlining goals and pathways for developing the first fusion power plant. In June 2023, the BMBF adopted relevant recommendations and released the *Position Paper on Fusion Research* [10], further clarifying the framework conditions for fusion realization and the action areas and strategic directions for both magnetic confinement and laser inertial fusion research.

Second, Germany has increased research funding and established a prototype power plant special program. In September 2023, the BMBF announced it would add €370 million in fusion research funding over the next five years, with total investment exceeding €1 billion by 2028 to fund both magnetic and laser fusion, promoting industry and research institutions to jointly address power plant technical challenges. In March 2024, the BMBF released the research and development roadmap *Fusion Funding Program 2040* (Fusion 2040) [11], aiming to establish an application-oriented fusion research ecosystem composed of industry, startups, and the scientific community, with the goal of building a fusion prototype power plant around 2040.

1.4 Japan: Strengthening Multi-Sector Collaboration to Actively Capture International Markets

Japan attaches great importance to energy security, lists nuclear fusion as a national strategic technology field, and promotes technology R&D and industrial cultivation in an integrated manner to seize the high ground in fusion development.

First, Japan has released its first national fusion research strategy. To ensure energy supply security, Japan considers fusion energy an important source supporting future super-smart societies. In April 2023, it launched the *Fusion Energy Innovation Strategy* [12], establishing two pillars: technology R&D and industrial cultivation, aiming to manufacture commercial fusion devices ahead of others through government-industry-academia collaboration and achieve fusion power generation by 2050. In technology R&D, the strategy supports exploration of miniaturized, original emerging technologies, accelerates nuclear reactor concept verification, and advances related basic research. In December 2023, the Council for Science, Technology and Innovation (CSTI) listed fusion as a research direction for its "Moonshot R&D Program." In industrial cultivation, the strategy promotes alignment between technology and industrial development needs, supports fusion enterprise R&D activities and scenario innovation, particularly increasing support for startups, and actively participates in international industrial chain layout. For example, it expands areas that can integrate with existing or new technologies in other fields, including AI, big data, quantum communication, and power generation.

Second, Japan has established a dedicated promotion and guarantee mechanism. In March 2023, driven by the Council for Science, Technology and Innovation—Japan's "command tower" for science and technology decision-making—Japan established the Fusion Energy Industry Association (J-Fusion), bringing together manufacturing enterprises, general contractors, and technology companies to strategically advance fusion innovation and industrialization.

Third, Japan is strengthening technology security guarantees. The government plans to formulate measures from an economic security perspective to eliminate technical bottlenecks and allocate resources intensively to selected key areas.

1.5 Comparison of National Strategic Orientations

In summary, major countries have formulated a series of policies based on their research and industrial foundations, aiming to establish their own fusion industrial systems and innovation ecosystems as early as possible and achieve fusion power generation ahead of others globally. The main characteristics of these strategies are:

(1) **Clear Industrial Development Pathways**: Based on their development foundations, countries have formulated independent medium- and long-term fusion development strategies. The U.S., UK, and Germany target 2040 as the deadline for seizing the prototype power plant high ground, while Japan has set 2050 as its target. These strategies not only emphasize fusion's role in mitigating greenhouse gas emissions and limiting global warming but also specify concrete goals and roadmaps for commercialization.

(2) **Increased Research Funding**: With ITER project delays and deteriorating geopolitical environments, countries are further strengthening independent research capabilities to master technological high ground first. Germany and Japan have established special fusion research programs. The UK increased research funding by approximately £760 million after exiting the Euratom fusion program. The U.S. provided over $1 billion in support for Fusion Energy Sciences (FES) through the CHIPS and Science Act.

(3) **Promotion of Public-Private Collaboration**: In project implementation, countries encourage private enterprise participation in technical breakthroughs or support collaboration between research institutions and enterprises in site selection, demonstration, and other aspects. The U.S. attempts to attract various social capital funds for fusion development partnerships by promoting and pooling local government, private, and social capital, as well as new partnerships, to address scientific, technical, and commercialization challenges in critical application pathways. Japan's Fusion Energy Industry Association aims to establish "industry-academia-government" partnerships, planning to develop fusion technology and industrial roadmaps with technology readiness levels to promote fusion commercialization.

(4) **Strengthening Allied Strategic Cooperation**: In the past two years, the U.S. has successively established strategic partnerships with the UK, Japan, and others to jointly advance fusion power plant demonstration and commercialization. The UK Atomic Energy Authority (UKAEA) has reached cooperation agreements with Canada's General Fusion to conduct

commercial tests of Magnetized Target Fusion (MTF) technology. Japan proposes to continue sending personnel to ITER and JT-60SA and other large-scale domestic and international programs to cultivate strategic fusion talent.

(5) **Relaxing Regulatory Policy Constraints**: The U.S. Nuclear Regulatory Commission (NRC) is advancing regulatory modernization reforms, adopting pre-licensing mechanisms, risk-informed and technology-inclusive approaches, and licensing management measures to adapt to fusion energy development needs. The UK has formulated a more flexible and adaptive regulatory framework for fusion energy facilities, with fusion power plants exempt from licensing constraints applicable to traditional nuclear power plants.

2 Global Nuclear Fusion Research and Industry Trends

After decades of development, controllable nuclear fusion has progressed from theoretical research to basic scientific experiments, gradually advancing toward the demonstration reactor construction stage. Currently, nuclear fusion primarily relies on two technical routes—magnetic confinement fusion and inertial confinement fusion—to continuously advance toward commercial goals.

2.1 Breakthrough Achievements in Operational Experiments

Countries are actively developing independent fusion projects, with global fusion experimental devices exceeding 100 units. New achievements continue to emerge in plasma theoretical research and operational experiments, continuously setting new records. Meanwhile, fusion approaches are diversifying, with concepts and ideas such as stellarators, magnetic mirrors, reversed field pinches, spherical tokamaks, ultrasonic fusion, and microwave heating fusion being continuously proposed and verified. Z-pinch fusion research remains in its infancy and still requires extensive experimental verification of its feasibility.

Internationally, the U.S. National Ignition Facility (NIF) has successfully achieved net energy gain four times, demonstrating the feasibility of nuclear fusion as a potential clean energy source. The world's largest stellarator device, Wendelstein 7-X, has achieved record-high energy turnover, proving the potential of stellarator designs in controlling plasma behavior. The Joint European Torus (JET) fusion experiment achieved an energy output of up to 59 megajoules, nearly four times the previous record, marking progress in fusion energy gain (the ratio of input to output energy). The world's largest fusion reactor, JT-60SA, successfully ignited and entered full experimental phase. Russia's T-15MD tokamak device achieved stable plasma for the first time.

Domestically, China's fusion basic research has achieved remarkable results. In April 2023, EAST created a record of 403 seconds of steady-state high-confinement plasma operation. Independently developed water-cooled magnets successfully generated a steady-state magnetic field of 420,200 gauss, breaking the world record of 414,000 gauss set in 2017. These achievements provide important references for global fusion commercial application, particularly in solving key technical challenges such as long-duration steady-state operation and magnetic confinement.

2.2 Phase Progress in International Cooperation

Despite delays in the International Thermonuclear Experimental Reactor (ITER) project, some progress has been achieved. On July 1, 2024, ITER reached an important milestone: after two decades of design, production, manufacturing, and assembly, the large toroidal field coils were successfully completed and delivered in Japan and Europe. These are among the largest superconducting magnets ever manufactured. The U.S., Japan, UK, and Germany have all provided support in technical assistance, component manufacturing, and prototype design. China has undertaken 12 sub-package manufacturing tasks, including production of some superconducting cables, coil jacket fabrication, and vacuum vessel support system manufacturing.

2.3 Frequent Achievements in Applied R&D

Enabled by innovative technologies, compact fusion devices have received preliminary validation, and various capital sources have increased support for application exploration. General Atomics released a stable, compact advanced tokamak fusion pilot plant concept. Zap Energy's technical enterprise developed a compact reactor that broke through 10 million degrees Celsius. The National Institute for Fusion Science in Japan and U.S.-based TAE Technologies collaborated to achieve hydrogen-boron fusion experiments in magnetically confined fusion plasma for the first time, proving the feasibility of neutron-free fusion. Oxford University's First Light Fusion company successfully implemented projectile fusion technology experiments, planning to build a 150-megawatt demonstration power plant before 2030. Germany's Technical University of Darmstadt's Focused Energy company, using the laser inertial confinement fusion route, plans to establish its first fusion energy pilot power station by 2035. China's Energy Singularity company successfully achieved plasma discharge with its "Honghuang 70" high-temperature superconducting tokamak device.

2.4 New Materials and Technologies Improving Feasibility

High-temperature superconducting technology is expected to promote the miniaturization of fusion devices. MIT's Plasma Science and Fusion Center achieved important progress, with a research team using Rare Earth Barium Copper Oxide (REBCO) to create the world's highest magnetic field strength high-temperature superconducting magnet, reducing reactor volume by 30 to 40 times compared to traditional designs and potentially reducing cost per watt to 1/40 of the original. A research team at the State University of New York at Buffalo successfully prepared REBCO-based superconducting wires, achieving the highest reported critical current density and pinning force to date. China's Lianchuang Superconducting company successfully developed hundred-meter-level bundled cables for nuclear fusion applications, which can significantly reduce the construction and operation costs of tokamak devices.

AI and other applications are helping break through fusion technical bottlenecks. UK-based DeepMind collaborated with scientists from EPFL to improve control of ultra-high-temperature plasma in real reactor environments based on deep reinforcement learning algorithms, increasing plasma simulation accuracy to 65% and significantly reducing long-term deviations in plasma current. Princeton University and the Princeton Plasma Physics Laboratory jointly developed an AI model for real-time prediction of plasma instability in fusion reactors.

2.5 Capital Boosting Rapid Industrial Chain Development

Currently, R&D competition in the controllable nuclear fusion field has quietly begun, and commercialization is advancing rapidly. Driven by private capital and diversification of the fusion supply chain, the number of global private fusion companies has grown from 5 in 2017 to about 50 in 2023, covering upstream basic materials and equipment manufacturing, midstream reactor design and component production, and downstream application scenario development. According to statistics from the U.S. Fusion Industry Association in July 2024 [13], cumulative global public investment in fusion research reached $426 million, an increase of over 50% compared to the full year of 2023, with the global market size expected to reach $500 billion by 2030. The 45 global fusion companies surveyed had secured $7.1 billion in financing (a 14.5% increase), with a considerable portion coming from tech giants like Microsoft and Google. Among them, 21 companies plan to achieve fusion power grid connection between 2030-2035, significantly ahead of government projects.

Fusion technology application scenarios and market potential have made significant progress, extending beyond power generation to industrial, aerospace, and medical fields. In industrial heat utilization, high-temperature heat generated by fusion reactions can provide stable high-temperature heat sources for chemical, metallurgical, and cement manufacturing, reducing dependence on fossil fuels. In micro-energy grids, miniaturized fusion reactors can provide efficient energy solutions for remote mountainous areas and islands. In green hydrogen production, clean electricity from fusion reactions can be used for electrolytic hydrogen production, enabling large-scale, low-carbon hydrogen production. In aerospace, the high energy density of fusion reactors makes them ideal propulsion systems for future space exploration, providing continuous high-power propulsion for deep space travel. In medical applications, efficient fusion reactions can enable more precise tumor treatment with reduced damage to healthy tissue.

3 China's Fusion Layout and Current Situation Analysis

China's fusion research is synchronized with international progress, with fusion reactors still in the early research stage. EAST has created new operation records, CFETR is progressing smoothly, fusion industry alliances and controllable nuclear fusion innovation consortiums have been established, and Energy Singularity's "Honghuang 70" device has achieved over 96% domestic production rate. In 2022, China's Fusion Industry Alliance and Controllable Nuclear Fusion Innovation Consortium were established in Hefei and Chengdu respectively, aiming to gather domestic and international scientific research and industrial strengths to promote breakthroughs in nuclear fusion technology in power generation, industry, and other fields [2], and advance China's industrial chain development. However, compared with major countries, China's fusion research and industrial deployment still has some shortcomings, such as insufficient frontier research layout in AI and other technologies, relatively weak application-oriented research, and limited roles for private enterprises [14,15].

3.1 Insufficient Strategic Planning for Future Industries

Major countries have strengthened industrial application policy planning. Japan has formulated detailed technology and industrial roadmaps based on assessments of technological strengths/weaknesses and supply chain security. Although China has listed nuclear fusion as a strategic industry, its industrial development support policies remain relatively macroscopic and need to be refined and detailed. Moreover, as global industrial and technological supply chain competition intensifies, vigilance is still needed against potential U.S.-led Western technology, talent, and patent blockades on geopolitical grounds, such as the U.S.-UK joint statement accelerating fusion strategic cooperation.

3.2 Inadequate Funding Scale and Diversified Technical Layout

In 2024, the U.S. annual R&D budget for fusion science exceeded RMB 7.3 billion, with commercialization R&D funding exceeding RMB 6.1 billion. In contrast, China's magnetic confinement fusion special funding from 2008-2023 was approximately RMB 6 billion, with insufficient support for commercialization and inertial confinement routes. The U.S. has established multiple funding programs to support machine learning, advanced computing, and other research, while Japan has strengthened exploration of miniaturization technologies. China's specialized layout for diversified technical routes such as miniaturization and AI technology remains relatively weak.

3.3 Need to Enhance Independent Innovation Capacity in Fusion Research

No international device has yet achieved long-duration burning plasma states. China also faces unknown scientific challenges in advanced operating modes, confinement, and transport for burning plasma. The U.S. is designing and building the compact SPARC device for deuterium-tritium burning physics experiments, while ITER is not expected to conduct experimental research until around 2039. China's existing devices cannot conduct steady-state burning plasma experiments with fusion power gain, lacking accumulation in theoretical simulation and diagnostic technologies for deuterium-tritium burning plasma [16]. China has also paid insufficient attention to building key data resources, with weak independent capabilities in irradiation analysis evaluation and extreme environment simulation.

3.4 Incomplete Industrial Chain Support Systems

Countries are strengthening public-private R&D cooperation, providing funding and technical support for private enterprise R&D. The U.S. launched the "Milestone Program" to fund eight companies for pilot plant verification, while the UK signed cooperation agreements with multiple companies through its Fusion Industry Program. China's private enterprises such as ENN Technology, Energy Singularity, and Star Ring Fusion are also actively participating in technical route exploration, but their numbers still lag far behind the 25 in the U.S. China's technical threshold conditions are strict, with industry barriers and insufficient competition mechanisms. Additionally, China's engineering and technical talent pool has gaps.

4 Conclusions and Implications

The global controllable nuclear fusion R&D competition is intensifying, with national strategic directions further targeting independent supply chain systems. Driven by multiple factors including technological breakthroughs, international cooperation, policy support, and capital influx, industrial development has entered a fast lane. Although the fusion industry has enormous development potential and market prospects, fusion research is gradually transitioning from the basic scientific experiment stage to the demonstration reactor construction stage, which is insufficient to support commercial applications at civilian power generation scale. Achieving ignition at hundreds of millions of degrees and burning plasma, neutron irradiation resistance, and demonstrating deuterium-tritium operation are the main challenges in fusion research [16]. Furthermore, the U.S. high-profile promotion of "ignition success" aims to push Congress to increase financial support, but may also have political motivations, potentially similar to past space races, deliberately creating anxiety to interfere with other countries' research routes and induce global capital to follow trends.

In response, China should maintain strategic resolve, fully consider the disruptive potential and risks of these technologies, and actively yet prudently promote fusion research and industrial development.

4.1 Strengthen Planning for Fusion Future Industry Development

The pathways of experimental devices, experimental reactors, demonstration reactors, and commercial application are inevitable stages in fusion energy development and application. Under the framework of the "three-step" nuclear energy strategy, China needs to clarify its fusion technology strengths, weaknesses, development prospects, and key challenges, independently propose fusion research and technology development roadmaps, refine stage goals and key directions for experimental devices—experimental reactors—engineering demonstration reactors—commercial application reactors, and rationally plan medium- and long-term objectives for fusion research. China should accurately grasp the functional positioning of fusion energy in energy structure transformation, strengthen complementary utilization with green hydrogen and other energy technologies, seize technology application tracks, strengthen nuclear fusion industry layout, propose breakthrough scenarios in the near term and scalable applications in the medium-to-long term, and actively promote comprehensive applications in aerospace, medical, and other fields.

4.2 Increase Support for Fusion Reactor Technology Research

China should coordinate major issues in controllable nuclear fusion R&D and strengthen core technology breakthroughs. Scientifically, this primarily involves solving essential technologies for future commercial fusion demonstration reactors not covered by ITER, including steady-state burning plasma control technology, magnetohydrodynamic instability control, tritium cycle and self-sufficiency, impurity transport theory and experiments, development of theoretical models and software tools for burning plasma performance prediction, and fusion energy output. China should establish competitive basic research projects, strengthen support for interdisciplinary fields such as machine learning and AI, and support exploration of new concepts and miniaturization routes.

In terms of device platforms, China should accelerate the construction and operation of compact fusion reactor experimental devices, support the development of experimental devices and verification platforms needed for pilot and engineering reactors, and vigorously strengthen independent construction of national fusion reactor data resources to establish integrated scientific data platforms for verification, simulation, diagnosis, prediction, and engineering technology.

In terms of engineering technology, China should research and establish major tasks for large-scale fusion reactor commercial power generation technology, reasonably increase central financial support for fusion reactor technologies with large application prospects, certain foundations, and urgent need for engineering, and increase the proportion of funding for applied research stages. China should establish specialized fusion commercial reactor research institutions to concentrate full-chain strengths in experimental verification, engineering design, and equipment development to accelerate domestic commercial reactor development.

In industrial applications, China should promote domestic R&D of core technologies and key components, strengthen policy deployment oriented toward industrial applications, and increase fiscal and tax subsidies as well as rolling project support for domestically produced materials and components led by enterprises or applied in enterprises.

4.3 Build an Independent and Autonomous Fusion Industrial System

China should formulate guidance opinions for the fusion future industry and deploy the fusion industrial chain around the fusion innovation chain. China should improve diversified capital investment, establish a fusion future industry development fund funded by state-owned assets to support key technology breakthroughs for fusion engineering demonstration reactors, and guide social capital to provide financial and insurance services for new technology route verification. As technological progress continuously lowers the threshold for private enterprises to enter the nuclear fusion field, China needs to further standardize industry approval and supervision procedures, appropriately and reasonably relax technical access requirements, and encourage the absorption and incubation of a batch of subdivided field technology enterprises in general materials and technologies, computational simulation, operation and maintenance, and other areas.

4.4 Strengthen Science and Technology Talent Team Building

Currently, the scale, structure, and level of China's nuclear fusion technology and engineering talent team are far from meeting planning needs. Going forward, China must increase cultivation of basic fusion professionals, continuously improve undergraduate education and master's and doctoral training systems, and expand high-level professional talent pools. Relying on resources and capabilities of existing nuclear industry groups or nuclear-related higher education institutions, China should establish high-end, professional training or re-education institutions as soon as possible to comprehensively improve practitioners' technical levels. China should increase engineering technology talent training quotas for universities, research institutes, and enterprises undertaking major national tasks and strengthen interaction between research and industrial talent.

4.5 Steadily Promote International Science and Technology Cooperation

China should continue to use the ITER joint program platform to conduct international frontier fusion research, strengthen exchanges of scientific talent and knowledge, and consolidate the solid foundation for domestic magnetic confinement fusion R&D. China should leverage its nuclear science and technology advantages to actively build science and technology cooperation platforms, introduce more high-tech solutions, and promote cooperation with interested and needy countries in fusion technology and nuclear safety research.

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Author Contributions

Li Lanchun: paper writing, data compilation; Liu Qing: revision guidance; Chen Wei: topic selection guidance.

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