Strengthening the Construction of Application-Supporting Major Scientific and Technological Infrastructures to Enhance China' s Scientific and Technological Foundational Capabilities for High-Quality Development (Postprint)

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Abstract

From "Two Bombs, One Satellite" to "China' s Eye of Heaven" (FAST), from having nothing to achieving world leadership, China has unwaveringly pursued a path of independent innovation with distinctive characteristics. Major scientific and technological infrastructure has undergone development for nearly half a century, with new breakthroughs achieved in multiple key fields, while the positioning, connotation, and classification of major scientific and technological infrastructure continue to evolve under the new circumstances. Based on in-depth investigations of major scientific and technological infrastructure such as the high-efficiency low-carbon gas turbine test facility, this article contends that the construction of application-supporting major scientific and technological infrastructure in China still faces challenges and issues, including a relatively insufficient user community and inadequate implementation of the transformation of scientific and technological achievements. In response to the significant opportunities presented by China' s new round of scientific and technological revolution and industrial transformation, as well as the urgent need to achieve self-reliance and self-improvement in science and technology and high-quality development, this paper proposes three countermeasures and recommendations: optimizing management systems for project initiation, construction, and acceptance; strengthening the operation, management, and evaluation of application-supporting major scientific and technological infrastructure; and increasing support for the transfer, transformation, and industrialization of technological achievements, hoping to provide reference and basis for the future planning, management mechanism improvement, and development policy formulation of application-supporting major scientific and technological infrastructure.

Full Text

Preamble

As a critical component of the national scientific and technological innovation system, major science and technology (S&T) infrastructure serves not only as a foundational platform supporting scientific research and high-tech development but also as a vital indicator of national comprehensive strength and scientific innovation capacity. In this new era, major S&T infrastructure—particularly application-oriented facilities—has become increasingly prominent in driving solutions to critical scientific and technological problems that constrain economic and social development, strongly supporting national strategic needs and industrial development. These facilities have gradually emerged as “national treasures” for cultivating new productive forces and promoting China’ s high-quality development. To deepen discussions on institutional arrangements and functional positioning for major S&T infrastructure construction in the new era, the *Bulletin of the Chinese Academy of Sciences* has organized this special issue themed “Theory and Practice of Major S&T Infrastructure Construction in the New Era,” focusing on systematically elaborating approaches to strengthen China’ s scientific and technological foundation for high-quality development, aiming to provide new perspectives for readers and support for decision-making.

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Strengthening the Construction of Application-Supported Major Science and Technology Infrastructure to Enhance China’ s Scientific and Technological Foundation for High-Quality Development

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Abstract

From “Two Bombs and One Satellite”to the Five-hundred-meter Aperture Spherical Radio Telescope (FAST), China has unswervingly pursued a distinctive path of independent innovation, advancing from ground zero to world leadership. After nearly half a century of development, major S&T infrastructure has achieved new breakthroughs in multiple key fields, while its positioning, connotation, and classification continue to evolve under new circumstances. Based on in-depth investigations of major S&T infrastructure such as the High-Efficiency and Low-Carbon Gas Turbine Test Facility, this article argues that China’ s construction of application-supported major S&T infrastructure still faces challenges including a relative lack of user communities and inadequate implementation of scientific and technological achievements transformation. In response to the major opportunities presented by the new round of scientific and technological revolution and industrial transformation, and the urgent need to achieve sci-tech self-reliance and high-quality development, we propose three countermeasures: optimizing management systems for project initiation, construction, and acceptance; strengthening operation, management, and evaluation of application-supported major S&T infrastructure; and increasing support for technology transfer, transformation, and industrialization. These recommendations aim to provide references and foundations for future planning, management mechanism improvement, and policy formulation for application-supported major S&T infrastructure.

Keywords: application-supported major infrastructure, major scientific and technological infrastructure, high-quality development, high-efficiency and low-carbon gas turbine test facility

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1.1 Background and Role of Major S&T Infrastructure Construction

President Xi Jinping has emphasized: “We must scientifically plan and layout forward-looking, strategy-oriented, and application-supported major S&T infrastructure, strengthen supervision during and after facility construction, improve whole-lifecycle management, and comprehensively enhance open sharing levels and operational efficiency.” China is currently facing a new round of scientific and technological revolution and industrial transformation, with economic growth drivers shifting from factor-driven to innovation-driven models. High-quality development urgently requires application-supported major S&T infrastructure as a new engine to advance breakthroughs in new industrialization, agricultural modernization, energy revolution, life and health, and ecological environment. Accurately understanding the challenges and problems in constructing application-supported major S&T infrastructure and strengthening such construction are of major strategic significance for implementing the national innovation-driven development strategy, enhancing China’ s scientific and technological foundation, breaking through frontier research applications and industrial key technologies, and achieving high-quality development.

Major S&T infrastructure constitutes an important part of the national innovation system and plays crucial roles in national security, economic development, scientific research, talent cultivation, and natural exploration. It addresses sustainable development and national security issues, providing scientific and technological support for major strategic decisions; pursues international scientific frontiers to enhance China' s original innovation capabilities and advance fields such as high-energy physics and molecular biology to international leadership; gathers high-tech industries and cultivates innovative leading talents to promote comprehensive high-quality regional economic and social development; meets people' s growing needs for a better life by providing systematic scientific solutions in life and health, low-carbon environmental protection, and major disaster prevention and control; and demonstrates China' s image as a sci-tech powerhouse while making historic contributions to humanity' s exploration and understanding of nature.

1.2 Layout and Significance of Major S&T Infrastructure in Developed Countries

Currently, international sci-tech competition is unprecedentedly fierce, with scientific and technological innovation becoming the key variable for seizing opportunities in crises and opening new prospects amidst changes. As critical support for revolutionary breakthroughs at scientific frontiers, major S&T infrastructure has been actively constructed and strategically deployed by major developed countries and economies—including the United States, United Kingdom, France, Germany, Japan, and the European Union—since the World War II-era Manhattan Project, all striving to seize the commanding heights of future technological development.

The United States employs both long-term and short-term planning approaches. Under the management of the Department of Energy (DOE) and the National Science Foundation (NSF), the U.S. actively deploys frontier research in particle physics, ultrafast science, and adaptive optics, relying on major S&T infrastructure such as the Advanced Photon Source (APS), James Webb Space Telescope (JWST), Large Synoptic Survey Telescope (LSST), and Deep Underground Neutrino Experiment (DUNE) to maintain its leading position in sci-tech innovation. In 2021, the White House Office of Science and Technology Policy (OSTP) National Science and Technology Council (NSTC) released the *National Strategic Overview for Research and Development Infrastructure*, stating that the U.S. would plan, invest in, and deploy necessary knowledge infrastructure and research network infrastructure.

The European Union coordinates multilateral relations through the European Strategy Forum on Research Infrastructures (ESFRI) and has planned and constructed technologically complex large-scale facilities, including the Large Hadron Collider (LHC) and European Synchrotron Radiation Facility (ESRF), which rank among the world' s leading major S&T infrastructure. In 2021, the EU released the *Strategy Report on Research Infrastructures Roadmap 2021*, indicating that its major S&T infrastructure layout focuses on big data, computational communication, energy and environment, food and health, astronomy and geophysics, and social and cultural fields, with plans to construct 11 new facilities including the European Brain Research Infrastructure (EBRAINS), European Social Mining and Big Data Analytics Integrated Infrastructure (SoBigData++), and Marine Renewable Energy Research Infrastructure (MARINERG-i).

The United Kingdom, France, Germany, Japan, and other developed countries have also actively planned and constructed major S&T infrastructure to support emerging pillar industries. To address the Fourth Industrial Revolution, the UK, under the investment of UK Research and Innovation (UKRI) and management of the Science and Technology Facilities Council (STFC), has oriented facility construction toward data science, supercomputing, risk management, and talent infrastructure, achieving accomplishments in organic and electronics industries. The UK Spallation Neutron Source (ISIS) alone has created over £13 billion in value. France, relying on the National Center for Scientific Research (CNRS) and National Institute of Health and Medical Research (INSERM), has focused on energy transition, data management, and biological health issues while actively transforming toward multi-point distributed virtual network platform-style soft facilities. Germany, under the investment of the Federal Ministry of Education and Research (BMBF) and management of the Helmholtz Association (HGF), has formed long-term partnerships between major S&T infrastructure, societies, universities, and research institutions, with research directions expanding beyond traditional disciplines like astronomy and physics toward next-generation trains, automobiles, and humanities and social sciences that can better drive industrial technology upgrades. With the rise of the global open science movement, Japan, under the design and planning of the Council for Science, Technology and Innovation (CSTI), released its *6th Science and Technology Innovation Basic Plan*, shifting the focus of major S&T infrastructure layout from traditional fields like medicine, automotive, and food to technologies needed for the "Society 5.0" era, including cyber-digital, low-carbon energy, and disaster and epidemic prevention. Additionally, countries like the Netherlands, Sweden, Denmark, and the Czech Republic have each developed strategic development roadmaps for S&T infrastructure tailored to their national conditions.

1.3 Development History of Major S&T Infrastructure in China

In the early 1960s, with the construction of various small research facilities for the "Two Bombs and One Satellite" program, China' s major S&T infrastructure began to emerge. The *1956-1967 Long-Range Plan for Scientific and Technological Development* established the guiding principle of "focused development to catch up," and in 1966, China' s first major S&T infrastructure—the Long- and

Short-Wave Time Service System—was approved for construction by the former State Science and Technology Commission [Figure 1: see original paper].

After reform and opening up, major S&T infrastructure construction entered a growth period. Deng Xiaoping' s assertion that "science and technology are the primary productive forces" and the signing of the China-U.S. Science and Technology Cooperation Agreement spurred the construction of facilities such as the China Remote Sensing Satellite Ground Station, Beijing Electron-Positron Collider, Lanzhou Heavy Ion Accelerator, Beijing Tandem Accelerator, and Hefei Light Source, marking the beginning of comprehensive, multi-disciplinary development.

Since the 1990s, major S&T infrastructure construction entered a development period. With the "Rejuvenating the Nation through Science and Education" strategy proposed by the Party Central Committee, 11 major S&T infrastructure projects were launched, including the Guo Shoujing Telescope, Shanghai Synchrotron Radiation Facility, China Crustal Movement Observation Network, and Experimental Advanced Superconducting Tokamak (EAST). The 11th Five-Year Plan formally incorporated major S&T infrastructure into national five-year plans, emphasizing the enhancement of original innovation capabilities and scientific foundation. With support from the former State Planning Commission and the current National Development and Reform Commission, 12 major S&T infrastructure projects began key construction, including the China Spallation Neutron Source, FAST, Steady High Magnetic Field Facility, and Icing Wind Tunnel.

Since the 18th Party Congress, major S&T infrastructure has entered a high-speed development stage, with the Party Central Committee coordinating planning and systematically deploying sci-tech innovation, achieving historic leaps in construction. During the 12th and 13th Five-Year Plan periods, 26 major S&T infrastructure projects were launched, including the Large High Altitude Air Shower Observatory, High-Efficiency and Low-Carbon Gas Turbine Test Facility, and High Energy Photon Source. The 14th Five-Year Plan proposes constructing another 20 facilities, representing a leap in both quantity and quality and ushering in a period of rapid development. As of June 2023, China has nearly 60 major S&T infrastructure projects, with major breakthroughs achieved in multiple frontier fields, successfully joining the ranks of innovative nations.

1.4 Severe Shortage of Application-Supported Major S&T Infrastructure

Major S&T infrastructure can be classified into three categories based on scientific purpose: specialized research facilities, public experimental platforms, and public welfare infrastructure—a standard widely applied currently, though the connotation, classification, and target fields continuously evolve with scientific and social development. The 14th Five-Year Plan divides major S&T infrastructure into four categories: strategy-oriented, application-supported, forward-looking, and livelihood-improving.

Major S&T infrastructure construction must avoid “neglecting the near for the distant” and “detaching from reality toward abstraction” ; instead, we should strengthen the construction of application-supported major S&T infrastructure. Currently, most completed major S&T infrastructure in China can be classified as forward-looking, oriented toward world sci-tech frontiers, undertaking basic research tasks of “from 0 to 1,” enhancing original innovation capabilities, and addressing national security bottlenecks. However, relative to the urgent needs of China’ s national economic pillar industries and strategic emerging industries, application-supported major S&T infrastructure is severely insufficient.

Application-supported major S&T infrastructure is market-oriented by technology breakthroughs and national needs, dedicated to transforming basic research results into practical applications that generate tangible economic, social, or policy benefits. Typically constructed to address industrialization challenges such as difficult technological breakthroughs and scarce testing and verification environments for core technologies or equipment in national economic pillar industries and strategic emerging industries, these facilities serve dual functions of scientific research and engineering application, providing experimental platforms and testing means for users across multiple fields to maximize service to engineering applications and industrial development in key areas. China is currently facing major opportunities from a new round of sci-tech revolution and industrial transformation, making it imperative to accelerate construction of application-supported major S&T infrastructure as a new engine for economic growth and enhance China’ s scientific and technological foundation for high-quality development.

1.5 Related Cases of Application-Supported Major S&T Infrastructure

Application-supported major S&T infrastructure effectively facilitates breakthroughs in new industrialization, agricultural modernization, energy revolution, life and health, and ecological environment. For example, the High-Efficiency and Low-Carbon Gas Turbine Test Facility focuses on major basic theories and key technologies for clean utilization and efficient conversion of fossil energy, providing an innovation platform for sustainable, low-carbon, and high-quality development of fossil energy. With the powerful technical support of such infrastructure, breakthroughs in key core technologies can be achieved to realize independent control in key areas and critical links, representing an important focal point for advancing new industrialization. For instance, high-energy synchrotron radiation facilities can conduct comprehensive experimental research on industrial application problems, combining multiple disciplinary methods to uncover sources of industrial innovation.

Deep integration of digital technology is an important path to achieving new industrialization. Industrial sectors need to fully utilize digital and intelligent technologies to improve production efficiency and product quality, driving industries toward high-end and green transformation. Future network test facilities, as application-supported infrastructure, are crucial supports for intelligent network innovation and transformation, serving as foundational productive forces for industrial upgrading and transformation.

The Accelerator-Driven Transmutation Research Facility was constructed to address the safe treatment and disposal of long-lived, high-level radioactive waste from China’ s rapidly developing nuclear power industry. The Future Network Test Facility aims to solve the scarcity of internet operation and service test verification environments, supporting the rapid development of network science and cyberspace technology research in China. The Hypergravity Centrifugal Simulation and Test Facility provides essential support for high-performance material development, deep-earth and deep-sea resource exploitation, and large-scale infrastructure construction.

2 Urgent Need for Application-Supported Major S&T Infrastructure for High-Quality Development

Strengthening application-supported major S&T infrastructure construction to enhance scientific and technological foundation capacity is the necessary path for China to achieve high-quality development. Currently, China’ s sci-tech innovation suffers from problems such as constrained key core technologies and insufficient original innovation capabilities, severely hindering high-quality development. To improve China’s basic capacity for sci-tech innovation—including pressure resistance, adaptability, hedging, and countermeasures—we urgently need to leverage the institutional advantage of “concentrating resources to accomplish major tasks,” strengthen application-supported major S&T infrastructure construction, and enhance China’ s scientific and technological foundation for high-quality development, facilitating comprehensive development in new industrialization, agricultural modernization, energy revolution, life and health, and ecological environment.

2.1 New Industrialization

Key core technological innovation is the continuous driving force for advancing new industrialization. China possesses the world’ s most complete industrial system but faces problems of being large but not strong, and comprehensive but not refined. Relying on application-supported major S&T infrastructure to break through key core technologies and achieve independent control in key areas and critical links is an important focal point for advancing new industrialization. For example, high-energy synchrotron radiation facilities can conduct comprehensive experimental research on industrial application problems, combining multiple disciplinary methods to uncover sources of industrial innovation.

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2.2 Agricultural Modernization

The basic requirement for building an agricultural powerhouse is agricultural modernization, with the key lying in agricultural sci-tech innovation. China’ s current agricultural modernization process lags significantly behind, with a considerable gap from international frontiers, and prominent issues including lagging infrastructure, rising costs, low technological levels, and few achievements transformation. Critical agricultural technologies such as germplasm resources, agricultural machinery and equipment, chemical fertilizers and pesticides, and water-saving cultivation urgently need breakthroughs, and the vast market demand of 1.4 billion people awaits further satisfaction. Achieving high-quality agricultural development and modernization requires further integration of agricultural research resources and aggregation of agricultural sci-tech strength, relying on major innovation platforms based on new agricultural S&T infrastructure to build an agricultural powerhouse with strong technological equipment, industrial resilience, and competitive capacity. For example, China’s first agricultural major S&T infrastructure— “Shennong Facility” —is dedicated to crop molecular design breeding research and application. Upon completion, it will contribute to the development of agricultural and life sciences research in China, laying the cornerstone for advancing toward an agricultural sci-tech powerhouse.

2.3 Energy Revolution

Emerging energy technologies have become the core driving force for global energy transformation toward green and low-carbon systems. As the world’ s largest energy consumer, China is unswervingly advancing the energy revolution, with its energy sector entering a new stage of high-quality development. Establishing a new power system with renewable energy as the mainstay, developing intelligent energy systems, promoting low-carbon and zero-carbon manufacturing, and achieving clean and efficient utilization of fossil energy have become new directions for energy industry development. Building a new power system dominated by renewable energy to achieve the “dual carbon” goals urgently requires new application-supported major S&T infrastructure. For example, the High-Efficiency and Low-Carbon Gas Turbine Test Facility and Accelerator-Driven Transmutation Research Facility are dedicated to solving key scientific and technological problems in gas power and nuclear power, respectively, providing concrete support for sustainable, high-quality energy development.

2.4 Life and Health

Life and health sci-tech innovation is an urgent need to safeguard people' s health. China still faces a complex situation with intertwined health influencing factors and coexisting multiple disease threats, with prominent issues including re-emerging infectious diseases, chronic diseases affecting younger populations, population aging, food safety, and occupational health. The construction of monitoring and prevention systems for major diseases and hazard factors, key infectious and endemic disease prevention and control, and environmental health monitoring and disinfection urgently needs strengthening. Planning new application-supported major S&T infrastructure is essential to accelerate the transformation and industrialization of scientific and technological achievements such as new drugs, monitoring equipment, and emergency products, continuously meeting people' s needs for life and health. The research and development of medical device engineering, whole-process drug quality control, and AI-assisted diagnostic decision-making technologies also need to rely on application-supported major S&T infrastructure to gather advantageous biomedical industries and support enterprises in integrating sci-tech resources to build new industrial technological advantages.

2.5 Ecological Environment

Innovation in the ecological environment sci-tech system in the new era provides fundamental and strategic support for "Beautiful China" construction. China' s ecological environment sector faces unprecedented pressure for carbon emission reduction, lagging ecological prevention and restoration technologies, and challenges in catching up with environmental protection material and equipment industries. Addressing China' s shortcomings in low resource utilization rates and underdeveloped environmental protection industries urgently requires planning new ecological environment application-supported major S&T infrastructure to promote forward-looking sci-tech innovation in ecological protection, environmental materials, and intelligent environment. Simultaneously, accelerating key technological innovation and application transformation in collaborative "three-waste" disposal and utilization, climate change model assessment, earth system pattern recognition, and greenhouse gas emission reduction is necessary to establish a clean and efficient resource recycling system, enhance supply capacity for ecological governance and environmental protection equipment, and strengthen the international competitiveness of China' s environmental protection industry. For example, the Earth System Numerical Simulation Facility will play a key role in addressing major issues such as climate change and environmental governance.

3 Problems and Reflections in Application-Supported Major S&T Infrastructure Construction—A Case Study of the High-Efficiency and Low-Carbon Gas Turbine Test Facility

Currently, China’ s application-supported major S&T infrastructure construction faces a situation of coexisting challenges and opportunities. For example, the High-Efficiency and Low-Carbon Gas Turbine Test Facility has fully entered a critical construction phase and is expected to be operational in 2024. China’ s existing heavy-duty gas turbine technology lags at least one generation behind advanced foreign levels, with significant gaps in core key technologies such as hot-end components, control systems, zero-carbon and low-carbon fuel combustion, and high-temperature materials, and insufficient independent innovation capabilities. The test facility can help achieve independent innovation and industrial application development of gas turbines. However, during the facility’ s project initiation, construction, and subsequent operation, three main problems exist, which to some extent reflect common issues in application-supported major S&T infrastructure.

3.1 Rapid Frontier Technology Breakthroughs Make Facility Construction Difficult to Keep Pace

The long construction cycle of application-supported major S&T infrastructure makes it difficult for scientific and engineering objectives to keep pace with international frontiers and industrial demands. The international situation is complex and volatile, with frontier sci-tech research advancing rapidly. Unlike facilities that require long-term accumulation to achieve breakthroughs in basic science, the extended construction cycle from planning, project initiation, and completion to operation may result in application-supported major S&T infrastructure being partially outdated upon completion, unable to meet the demands of frontier technological breakthroughs. The High-Efficiency and Low-Carbon Gas Turbine Test Facility was included in the *National Medium- and Long-Term Plan for Major Science and Technology Infrastructure Construction (2012-2030)* in 2013, approved by the National Development and Reform Commission in 2020, and planned for completion in 2024. More than a decade has passed since the plan’s release, while frontier technologies in this field have developed rapidly and application demands evolve daily. Foreign H-class gas turbines have already entered the market, while China’ s focus remains on developing E-class and F-class gas turbines. Against the backdrop of the “dual carbon” goals and increasingly severe international situations, gas turbines have been entrusted with more arduous new missions. These circumstances will directly lead to project optimization adjustments based on global gas turbine development and national major needs, causing difficulties and risks in project execution and acceptance regarding technical solutions and budget estimates.

Ultra-long planning and construction cycles can increase uncertainties in application-supported major S&T infrastructure construction, triggering a series of problems. While planning and constructing leading, high-level major S&T infrastructure is important, issues of how to construct, operate, and effectively use these facilities also require attention. The U.S. James Webb Space Telescope project, initiated in 1996 with an initial budget of $500 million and originally scheduled for launch in 2007, ultimately required a budget increase to $10 billion before its launch in late 2021—more than 25 years after project initiation. The development process encountered continuous unexpected issues, with launch delays occurring dozens of times, greatly increasing project costs. China' s Guo Shoujing Telescope was included in the Ninth Five-Year Plan in 1996, began construction in 2001, and after 13 years of construction overcoming numerous issues—including engineering feasibility exploration, difficulty in procuring key components, price inflation, budget insufficiency, project delays, serious talent loss, and team inexperience—finally passed acceptance in 2009. China' s application-supported major S&T infrastructure construction should optimize project initiation and process management, strengthen engineering technology team building, shorten construction cycles, reduce uncertainties, and bring facilities into operation earlier to realize their benefits.

3.2 Relative Lack of User Groups and Limited International Exchange and Cooperation

Application-supported major S&T infrastructure typically faces problems of limited user groups and high research barriers. Unlike some world-leading facilities in China, application-supported major S&T infrastructure has specific construction objectives, relatively narrow user group scope, high barriers for scientific research activities, and high testing costs coupled with imperfect intellectual property protection measures, causing potential users to hesitate and hold back. Taking the High-Efficiency and Low-Carbon Gas Turbine Test Facility as an example, its engineering objective is to meet current and future gas turbine component testing and research conditions that simulate real environments. Testing research features high parameters, high consumption, and long cycles, resulting in high testing costs that only some large enterprises and projects can afford. Moreover, such tests often involve users' key R&D links, and users' concerns about protecting core technologies and test data make them hesitant. These issues may lead to operational, open-access, and service benefits falling short of expectations after project completion, which in turn affects feedback regarding facility maintenance, upgrades, and renovations, resulting in a lack of corresponding demand and funding and preventing the formation of a virtuous iterative cycle.

Application-supported major S&T infrastructure has insufficient international influence and limited international exchange and cooperation. These facilities are often positioned in major technical fields related to national economy and national security. Especially under current circumstances where a few Western countries continue to escalate scientific and technological containment and blockade against China, coupled with the subsequent impact of the COVID-19 pandemic and insufficient international competitiveness of domestic projects, international sci-tech cooperation faces severe challenges. Facilities struggle to attract foreign users, leading to a lack of cooperative projects and user groups. In March 2021, FAST was officially opened to the world, approving 27 applications from 14 countries, contributing Chinese strength to the world. Application-supported major S&T infrastructure should learn from FAST' s philosophy and successful case of win-win cooperation with the international scientific community, deepening international exchange and cooperation and increasing international influence.

3.3 Inadequate Implementation of Scientific and Technological Achievements Transformation and Weak Enterprise Acceptance Capacity

The transformation and implementation of scientific and technological achievements from application-supported major S&T infrastructure remain inadequate. Since the 2015 revision of the *Law of the People' s Republic of China on Promoting the Transformation of Scientific and Technological Achievements*, the central government has issued numerous policy documents, basically resolving institutional and mechanism issues in sci-tech achievements transformation. However, due to different appeals and objectives, numerous problems exist in the interface between research institutes, universities, and enterprises, hindering actual transformation work. Taking gas turbines as an example, commercialization and industrialization of key components such as blades and combustion chambers require substantial R&D, testing, and verification processes, as well as time and capital investment, which cannot be completed by a single university or research institute alone. Most enterprises prefer to invest in introducing mature foreign technologies and products to avoid risks, daring not to invest in domestic new technologies and products, resulting in numerous advanced achievements being difficult to transform.

Chinese enterprises have relatively weak capacity to undertake and apply sci-tech innovation achievements from application-supported major S&T infrastructure. Large enterprises such as central state-owned enterprises and state-owned companies, constrained by performance assessment and risk prevention mechanisms, mostly tend to directly introduce mature foreign technologies or products. Between 2001 and 2007, China introduced over 60 sets of E-class and F-class heavy-duty gas turbines through market-for-technology approaches, initially mastering cold-end component manufacturing and complete unit assembly technologies, but key technologies such as complete system design and hot-end component manufacturing remain monopolized by foreign parties. Small and medium-sized enterprises, primarily manufacturers, have weak technological innovation and achievements transformation capabilities, making it difficult for them to undertake frontier sci-tech achievements produced by application-supported major S&T infrastructure. Regarding upstream small and medium-sized enterprises in China' s heavy-duty gas turbine industry, most are component manufacturers or raw material suppliers, while critical hot-end components such as turbine blades and combustion chambers remain highly dependent on foreign imports.

4 Countermeasures for Application-Supported Major S&T Infrastructure Construction

China is currently in a new stage of rapid development of major S&T infrastructure. Application-supported major S&T infrastructure, oriented by national and market needs, supports major technological breakthroughs in national economic and national security fields to achieve high-level sci-tech self-reliance. China should leverage its "whole-nation system" advantages, continue strengthening top-level planning and institutional construction, make sound strategic development choices, layout advantageous disciplines, and promote sci-tech achievements transformation. We must conduct organized, institutionalized scientific research, deepen whole-process user participation and high-level international cooperation, translate the driving effect of application-supported major S&T infrastructure into actual industries, and comprehensively realize facilities' scientific, engineering, and social objectives.

From the 11th to the 14th Five-Year Plan, top-level planning for application-supported major S&T infrastructure has gradually improved, with continuously increasing support from central and local governments and accelerating steps in relevant technological innovation and industrial revitalization. However, compared with developed countries, China still has gaps in major S&T infrastructure planning and design, management evaluation, open cooperation, and industrial transformation. How to leverage the institutional advantages of the "whole-nation system," learn from foreign facility construction and management experiences, make sound strategic development choices, layout advantageous disciplines, and promote sci-tech achievements transformation to translate facilities' driving effects into actual industries, this article proposes three recommendations.

4.1 Optimize Management Systems for Project Initiation, Construction, and Acceptance

(1) Strengthen national-level overall planning and top-level design for facility construction. Currently, local governments and even social capital have high enthusiasm for application-supported major S&T infrastructure, which can easily lead to disorderly competition in resources and talent. Based on China' s Five-Year Plans, we should formulate five-year construction and operation plans for facilities, considering both urgent national needs and long-term reserves, selectively constructing application-supported major S&T infrastructure, optimizing deployment of major scientific research tasks, improving management systems for project initiation, construction, and acceptance, and fostering a sound innovation ecosystem. For example, application-supported major S&T infrastructure undertaken by Beijing-area units should consider locating in Xiong' an to develop synergistically with Huairou Science City.

(2) Establish specialized decision-making bodies such as Development Planning Committees for application-supported major S&T infrastructure and fully leverage their leadership role. Clarify the responsibilities and authority of Development Planning Committees, including formulating strategic planning details, reviewing and approving project budgets, and supervising project implementation. Establish effective decision-making mechanisms, strengthen communication and coordination with Science and Technology Committees and User Committees, and ensure scientific and fair decision-making. Under the leadership of Planning Committees, continuously track and evaluate project planning and construction progress, making necessary adjustments to plans based on changing circumstances and deeper understanding to ensure smooth plan implementation and successful project completion and acceptance.

(3) Delegate some authority to construction units to accelerate project construction. Throughout the project construction cycle, from a management perspective, construction units should be granted adjustment and change authority for construction plans, procedures, procurement, and budget adjustments under the premise of unchanged scientific and engineering objectives and compliance with national laws and regulations. Construction units should formulate internal rules and regulations matching facility construction needs to ensure rapid, efficient, and high-quality facility completion and acceptance, enabling early functionality.

4.2 Enhance Operation Management and Evaluation of Application-Supported Major S&T Infrastructure

(1) Conduct organized research and explore new mechanisms for multi-facility, multi-user collaborative innovation. Fully utilize multi-user collaborative innovation mechanisms relying on multiple application-supported major S&T infrastructure to conduct organized, institutionalized research. For example, research institutes such as the Institute of High Energy Physics and Institute of Metal Research of the Chinese Academy of Sciences, relying on multiple facilities including the Spallation Neutron Source and Beijing Synchrotron Radiation Facility, actively cooperate with enterprises such as China Iron & Steel Research Institute Group and Aero Engine Corporation of China, forming integrated teams to jointly formulate experimental plans, conducting organized and systematic scientific research, and jointly tackling cutting-edge technologies such as engine blades and composite materials.

(2) Fully leverage the assisting role of User Committees to listen to actual needs of users, especially enterprise users. Application-supported major S&T infrastructure represents important national sci-tech resources invested in and constructed through national coordination, with scientific and engineering objectives reflecting urgent needs for high-quality development in relevant fields. The public service nature and resource scarcity of these facilities determine that open sharing is an essential requirement. To meet urgent needs in these fields and solve relevant major sci-tech problems, it is necessary to establish user teams from project initiation, continuously absorbing requirements for major S&T infrastructure from all user sectors.

(3) Establish classification evaluation and incentive mechanisms suited to the operational laws of application-supported major S&T infrastructure. Current evaluation systems for major S&T infrastructure primarily use indicators such as papers, patents, software copyrights, awards, operational hours, number of served users, operational staff, talent cultivation, and major achievements produced. As previously mentioned, the number of users for application-supported major S&T infrastructure is often difficult to compare with other types of facilities, directly resulting in lower evaluation scores that affect national funding allocation for facility operation, making it difficult to guarantee facility operation, maintenance, and upgrades, and directly impacting the stability and professionalism of facility operation teams. Therefore, we recommend conducting systematic investigations for application-supported major S&T infrastructure, understanding common situations and personalized problems for relevant facilities, conducting classified evaluations, with competent authorities conducting specialized policy research from management and evaluation perspectives to formulate adaptive evaluation systems that guarantee open sharing levels and operational efficiency after facility completion.

4.3 Increase Support for Technology Transfer, Transformation, and Industrialization

Taking major S&T infrastructure management units as the core, form research teams comprising management units, competent authorities, local governments, typical users, consulting institutions, and social capital to conduct work in four areas:

(1) Conduct forward-looking planning for sci-tech achievements transformation and industrialization development before facility completion. Clarify the positioning and development strategies of facilities in regional innovation systems and industry development, screen priority industries and industrial ecological systems relying on facilities, strengthen facility promotion and publicity, innovate management mechanisms and incentive measures to promote user enthusiasm for facility utilization, and explore innovative forms such as demonstration projects, insurance compensation, industrial alliances, and industrial funds to solve the "first-set" and "dare-to-use" problems.

(2) Focus on industry development pain points and explore transformation models, mechanisms, and paths for achievements generated by facilities. Fully leverage respective advantages of all parties to form synergistic effects and fundamentally improve sci-tech achievements transformation efficiency.

(3) Promote the construction of innovation ecosystems with "application-supported major S&T infrastructure–technology industry/incubation park–application demonstration base" as the main body. Lead technological progress and industry development with facilities.

(4) Take the High-Efficiency and Low-Carbon Gas Turbine Test Facility as an example. The facility is located in Lianyungang City, Jiangsu Province, and Pudong New Area, Shanghai. Lianyungang hosts the Xuwei Petrochemical Base, one of China' s seven major petrochemical industry bases, while Pudong New Area is building a high-end equipment manufacturing industry cluster with power devices as core technology. Relying on the facility' s powerful basic research, technology development, and test verification capabilities, and fully leveraging the high-end talent aggregation effect, technology radiation effect, and industrial agglomeration driving potential of major S&T infrastructure, the facility will serve the high-quality development needs of high-end manufacturing bases and petrochemical industry bases, constructing technology incubation parks and industrial parks for gas turbine components and complete machines, strengthening and supplementing industrial chains, forming a complete innovation chain from R&D verification, component development, complete machine integration, test demonstration, to industrial application, driving industrial transformation and upgrading, forming a virtuous cycle of innovation ecosystems, and providing important support for the independent development of China' s heavy-duty gas turbine technology.

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