

China's Strategic Options for S&T Development Toward 2020



North face of Mount Qomolangma toward the base camp. Credit: Luca Galuzzi

Major S&T Issues Deserve Higher Priority in Strategic Planning

The central authorities place great importance on the role of science and technology as the primary productive force and attach strategic priority to S&T innovation. Since 2002, when the 16th National Congress of the Communist Party of China convened, the government has set the strategic objective of building China into an innovation-oriented nation, implemented the Outline of the National Program for Long and Medium-Term S&T Development (2006-2020), and greatly increased S&T investment. In order to strategically deploy S&T resources in priority areas or research directions, the government launched programs such as the National Science Foundation of China, the National High Technology Research and Development Program of China (863 Program), the National Basic Research Program (973 Program), the National Key Technology R&D Program, National Major Science and Technology Projects, the Knowledge Innovation Program, and the Technology Innovation Program. Furthermore, the Twelfth Five-Year Plan for National Development paid close attention to major S&T tasks, including effectively fostering and developing emerging industries of strategic importance, boosting breakthroughs in core technological issues for priority industries, promoting breakthroughs in key S&T areas important for public welfare, accelerating the enforcement of national major S&T programs, making projected deployment of fundamental S&T research and cutting-edge technologies, and enhancing bases and platforms for S&T innovation. Their implementation will effectively help China build its innovation capacity, facilitate the achievement of S&T breakthroughs, make important contributions to major international S&T events, and speed up the building of an innovation-oriented country.

Meanwhile, we must be acutely aware that China has made inadequate arrangements in many areas and fields where rapid S&T advances and revolutions might take place. Therefore, accelerated and strengthened deployment should be made. We believe new major S&T issues should be addressed to satisfy national socioeconomic needs, foster possible S&T breakthroughs in China, and contribute to global S&T events. As such, new arrangements should be made on the basis of the existing structure to reinforce

vulnerable areas with focused efforts, effective organization and superior S&T forces.

1. Major S&T issues meriting accelerated or enhanced support in areas and directions vital to national socioeconomic progress

(1) Green process research for effective, clean utilization of resources

Manufacture industries consume lots of natural resources and energy, and discharge a majority of the pollution affecting the environment. Effective and clean utilization of resources plays a key role in green manufacture. For the staple mineral, oil and gas, and biomass resources of China, targeting at their unique complicated compositions and structures, research on mechanisms of matter transformation and methods for reaction, separation, transfer enhancement and control shall be encouraged, so as to establish a set of original integral technologies of green new process and clean production for effective and clean transformation/utilization of resources, as well as multi-dimensional simulation, integration and optimization technologies aimed at resources efficiency and environmental friendliness, so as to formulate computer-aided green design applications, and take a lead in the upgrading of green technology for traditional manufacture. Presently, the State has made many rendezvous in terms of process manufacture related to basic materials, but the deployment needs further enhancement in the aspect of fundamental research and original technological innovation.

(2) Low-cost preparation of high-end basic materials

China has been plagued with a low degree of self-sufficiency in terms of high-end structural materials and high-performance functional materials, with inadequate ability to substitute key strains of imported materials in large scale with its own products. For example, only less than 20% of the steel produced by China meets the world-class standard, and the advanced technique for polysilicon production has been monopolized by seven enterprises owned by the USA, Japan and other developed countries.



This has posed a bottleneck for the accomplishment of many major engineering projects. Therefore it is most pressing to address this problem by studying principles and methods to improve the comprehensive performance of materials, energy-saving and low-pollution technologies for materials preparation, smart and controllable technologies for materials processing with high efficiency and short procedure, and evolutionary laws for material performance as well as their quantitative presentation. Working in this direction, in ten years, we might be able to achieve self-sufficiency of high-end basic materials, and form a system of standards of our own characteristics. For the time being, what shall be enhanced might be research efforts to tackle key technical problems in preparation of major types of materials, as well as the engineering approach to solving such problems; on the other hand, a platform shall be erected for performance testing, data accumulation and standard research.

(3) Revolutionary technologies for nanoindustrial manufacturing

China has reaped numerous important achievements in fundamental research and applied fundamental research in nanotechnology, but it still needs to strengthen the driving role played by major national economic demands and promote R&D and applications in this field to boost the development of emerging industries. The nation shall further concentrate S&T forces to tackle major problems, with emphasis given to the following areas: to form China's own superior industries, special efforts should be made to systematically integrate nanotechnologies of revolutionary prospects, promote revolutionary innovations in green nano-printing technology and long-life lithium-ion fuel cells, and accelerate related demonstrative applications; to foster emerging industries, enhanced efforts should be made to develop technically mature nanotechnologies, to promote demonstrative applications of core technologies in fields including nano- design and manufacture of new drugs, power grid and crude oil transport, and break through technological problems restricting the development of national pillar industries; and to guarantee the healthy development of emerging industries, attention should be cast to the establishment of a standardized system of China for nanotechnology.

(4) Techniques for evaluation and exploitation of unconventional oil/gas resources, including tight sandstone reservoir of oil/gas and shale gas

China is weak in theoretical research and mining technologies for tight sandstone reservoir of oil/gas and shale gas, and unfortunately, quite often the theories,

methods and technical procedures established overseas are not directly applicable in China. Therefore emphasis should be laid on research in metallogenic theories, resources prediction and evaluation for such unconventional reservoirs against the geological tectonic background of China, so as to develop advanced drilling and mining technologies and equipment for such reservoirs suitable for the complicated geological conditions of China, providing support for scale and commercial mining of unconventional oil/gas reservoirs in China. This demands intensified efforts and uniform layout as well as deployment, calling for organized joint forces from involved departmental authorities, enterprises and research institutions to tackle key problems.

(5) Key technology for highly efficient reutilization of energy generated from organic waste

To address the dual pressure from environment and energy, it is pressing to research and develop near-zero-emission technologies for automatic airtight sorting, oxygen-rich pyrolysis and gasification, catalytic cracking of urban waste, and anaerobic combined hydrogen methane production, to form a technical system for comprehensive utilization of energy derived from urban waste. China needs to set up a series of equipment suitable for its own conditions for high-efficiency and clean utilization of organic waste, including equipment for automatic airtight sorting, oxygen-rich pyrolysis and gasification, and catalytic cracking of waste, and put it into demonstrative application, hence greatly upgrading the technical level of China in this field.

(6) Unconventional enriching mechanism and prospective evaluation for rare metals

Rare metals, including rare light metals, rare refractory metals, rare scattered metals and rare earth metals, are critical resources for emerging industries like new materials, new energy and information industries, playing a vital role similar to what oil does in modern society. Most rare metals boast great metallogenic potential in China, and it is imperative to select certain regions distributed with concentrated deposits of rare metals to thoroughly research their metallogenic mechanisms, so as to establish methods for prospective prediction and evaluation of rare metals, further evaluate resources potential and distribution, and provide S&T support for improving China's situation in terms of global resources allocation and achieving safe and high-value utilization of rare metals. So far, deployment in this aspect is inadequate, and hence strengthened efforts are needed to organize synergic forces from research institutions and mineral departmental authorities to solve related S&T issues.

(7) Technologies for prospecting and development of marine resources

Marine hydrocarbon resources constitute the majority of the remaining hydrocarbon resources of China. On the other hand, this country boasts abundant marine biological resources, possessing 1/8 of gross organism species of the planet. They both have invaluable potential for future prospecting and development. At present, revolving around two major scientific issues, namely the controlling role of continental margin in hydrocarbon accumulation in deep-water petroliferous basins and the development and evolution of deep-water carbonatite mesas, comparative research is needed to focus on the tectonic characteristics of the northern, western and southern continental margin of South China Sea (SCS), as well as on characteristics of sedimentary basins in these areas, so as to unveil the characteristics of petroliferous basins in such areas against different tectonic settings of the SCS continental margin, and difference between various systems of hydrocarbon accumulation. The development and exploitation of marine biological resources is of essential and strategic importance for China's food security and marine economy. It is suggested that a special national project should be set up specifically targeting at technologies for prospecting and development of marine resources.

(8) Technologies vital to sustainability of offshore environment

Marine ecological and environmental issues have become a major bottleneck restricting the sustainable development of China's marine economy. Offshore ecological disasters have been on the rise and ecosystems in turmoil, posing great threats to the sustainable utilization of marine biological resources. It is imperative to clearly understand the evolutionary laws of marine ecosystems under the dual pressure from natural and human activities, aimed at providing scientific evidence for formulation of marine strategies and accordingly reasonable development and utilization of marine resources. So far, research on harmful algae blooms and jellyfish blooms has been deployed, but synergic research on near-shore and offshore issues is rare due to the lack of long-term marine observations, and enhanced deployment in this area imminently needed.

(9) Basic theories and key technologies on underground new energy development

Underground new energy includes in-depth geothermal energy and gas hydrates. Geothermal energy abounds in southwestern, northern and northeastern

China and the coastal areas of southeastern China, and natural conditions in South China Sea and on the Tibetan Plateau are favorable for generation and accumulation of gas hydrates. Starting from research on mechanism and process of coupling effect involving temperature, liquid, mechanics and chemistry factors, China needs to gradually expand and develop comprehensive capability of theoretical research as well as technological R&D, and meanwhile research platforms shall be constructed for comprehensive experimental tests and verifying experiments, so as to build up its own international competitiveness. It is advised that interdisciplinary research of multiple dimensions be deployed on basic theories and key technological issues, preferably through setting up an S&T program or special projects.

(10) Causes and control of atmospheric haze

China is now suffering from increasingly serious complex atmospheric pollution; especially dust-haze has raised great concerns in general public and governmental authorities. So far, only scattered studies are seen in this field and understandings of its intrinsic causes remains too vague to answer questions including major driving factors and countermeasures. Therefore it is imminent to deploy systematic research in this area, so as to unveil the key pollutants and key mechanisms underlying the formation of haze, and accordingly develop technologies to battle this pollution. Meanwhile such research will also provide scientific and feasible technical as well as policy solutions for corresponding pollution control.

(11) Innovation and integration of industrial biotechnology

Synthetic biotechnology is still at an early stage of its development. By means of strategic deployment, China might be able to develop this sector abreast of advanced countries. What needs to be strengthened is comprehensive fusion of multiple disciplines including biology, chemistry, physics, computing science, and engineering science, with emphasis placed on bio-computing design, so as to achieve chemical synthesis and system optimization of organisms, promote integration between synthetic biotechnology and industrial manufacture, boost innovations in core technologies including bio-refinery, bio-catalysis, biological processing, and smart fermentation, develop industrial products of biotechnology including fuel, solvent, plastic, chemical and fiber, and achieve green update as well as industrialization of a series of industrial processing, including oil recovery, metallurgy, textile technology, papermaking, and pharmaceutical technology.



(12) New vaccines

New-generation vaccine is among the most economical and effective measures to prevent and control infectious diseases, to address bio-terrorism incidents, to secure public health and to maintain social stability. Deployment should be made targeting pathogenesis, immunological response/tolerance of hosts, and key technologies for vaccine development, to improve the effectiveness and safety of traditional vaccines, develop new-generation vaccines for major and emerging infectious diseases, and establish national stockpile of technology and drugs to combat major infectious diseases. So far, the nation has made some deployment in terms of important basic research and industrialization, but still enhanced integral layout is needed to concentrate forces from governmental, industrial, educational and academic sectors to make breakthroughs in vital technological issues, through fulfilling major national tasks.

(13) Mining and development of bio-resources of strategic importance

Biological resources lay a foundation for the survival of human beings and the development of society, not only providing food, medicine and industrial raw materials, but also playing an irreplaceable role in water and soil reservation, climate regulation, and biological control. We should take the following as priority areas in our R&D activities: biological resources and application aimed at future emerging bio-manufacture; bio-active matters aimed at healthy diet and new-type drugs for the country; and collection, systematic evaluation and purpose-oriented mining of strategic biological resources. We shall establish high-throughput and high-efficiency screening platforms and evaluation systems for strategic biological resources, and facilitate and hatch a wave of new bio-industries of promising competitiveness in the market. So far, a holistic deployment in this aspect is still missing, and systematic arrangement is advised by means of special projects and research programs, so as to centralize scattered forces to tackle targeted problems.

(14) A marine comprehensive observation system

Marine environment information, including information on ocean dynamic environment, ocean chemistry and sea creatures, is critical for economic development and national security, and could even as a vital factor determine the outcome of a war. Prompt mastery of dynamic information of ocean is of vital importance for climate, coastal defense, safeguard of maritime rights and interests, prevention and reduction of disasters, sustainable utilization of resources and ocean development. The establishment of a space-

aeronautics incorporation system of ocean observation holds a priority position in advanced countries when formulating their ocean strategies. China has been committed to the establishment of an ocean observational system, and has made some deployment in this field. Priorities for R&D in this aspect should include observational technologies, biological and chemical detectors, automatic maritime laying system for uses in sensitive regions, automatic observational technology, and real-time information transfer technology. It is imperative to enhance the systematic integration of ocean observational technologies and R&D of related key technologies, so as to break through the technology blockade against China.

2. Major S&T issues requiring further deployment and concentrated efforts in fields and directions where China may achieve significant breakthroughs

(1) Research and application of quantum information technology

Quantum information technology is strategically significant for safeguarding national information security. China is at world advanced levels in terms of quantum communication. Future research should focus on large-scale and extendable quantum information processing technology to build the foundation for China's application-oriented wide-area quantum communication technology, which will eventually help solve the nation's communication safety problem. We shall enhance the study of solid state quantum computer, quantum devices and related software systems, develop core units of quantum computing such as photons, cold atoms and quantum dots, and manage to achieve the coherent state manipulation of 50 to 100 quantum bits. We shall also strive to realize quantum simulations of complex systems using physical systems such as cold atoms. Hopefully in five to ten years' time, we can make an accurate judgment on the most suitable physical system for quantum computation to guide the long-term strategic deployment in the field.

(2) Materials design and process simulation

A systematic and precise understanding of the relationship between a material's organizational structure and its performance is an important basis for the accurate design and control of the material's preparation process. Today, computer-aided material simulation is a hotspot at the frontier of materials science. By investigating typical model materials and concrete key materials, future research should set up and verify simulation methods for typical applications and extreme conditions that are hard to realize

in the lab, to achieve more precise forecasting and promote the engineering application of new materials. With ten years of efforts, it is expected that China will cast off its role as an imitator and follower in new materials research and development, with an overall elevated innovation capacity which is closely connected to industries. To achieve this, systematic deployment and effective organization are needed so that research continuity from materials design to application can be established and the entire time span for materials development can be remarkably reduced.

(3) Stem cell and regenerative medicine

Stem cell and regenerative medicine research is very promising in helping address some of the major medical problems in China, including healthy birth, population aging, senility and heredity, and trauma- or disease-induced tissue and organ defects. In future, studies on the basic theories of stem cell biology, especially mechanisms that manipulate stem cell fate, should be enhanced. For technology transfer and application, research efforts should be arranged to focus on developing alternatives for induced pluripotent stem cell technology, aiming at theoretical and technological breakthroughs in the safe acquisition of functional cells and organs. As for government deployment, it is suggested to further support innovative research and enhance ethics-related studies.

(4) Innovative breeding systems based on molecular modules and complete genomes of agricultural animals and plants

It is extremely urgent for China to break overseas monopoly on modern breeding technologies and set up its own molecular module-based system for the selective breeding of agricultural animals and plants. In future, efficient breeding systems should be established via molecular modules and whole-genome association studies on the basis of genomics and systematic biology. By improving gene transfer and elite germplasm technologies for major grain and oil crops and livestock, poultry and aquatic animals in China, a new generation of high-yielding, good-quality and adversity-resistant agricultural species should be cultivated. For the moment, China is in lack of a systematic and integrated S&T program in this regard, and government efforts are needed for enhanced deployment.

(5) A new generation intelligent manufacturing system centered on ubiquitous information technology

By merging information technology with manufacturing technology, the ubiquitous information technology conforms to the manufacturing industry's

development trend towards digitalization and intellectualization, and thus constitutes the core and foundation of the next generation intelligent manufacturing. Research should focus on ubiquitous perception and network technologies, intelligent manufacturing technologies and intelligent robotics technologies for possible breakthroughs in a number of aspects, such as the establishment of ubiquitous information perception space, the processing of massive manufacturing information, machine understanding of human behavior and novel-type man-machine interaction, as well as informationized and automated manufacturing in the ubiquitous information perception space. By constructing a new manufacturing mode that highlights man-machine fusion, these studies aim to achieve a rigid connection and constraint between man and machine functions and progress toward their balanced intelligent collaboration. It is suggested that the government should launch special research programs to summon the efforts of research institutions and typical industries and enterprises to work together for a comprehensive breakthrough and lead the advancement of manufacturing technologies in China.

(6) Direct-current power grid technology

The research and development of direct-current power grid technologies should be enhanced immediately for the promotion of renewable energy in China. Studies on direct-current power grid theories, key materials and devices as well as core technologies and equipment should be conducted preferentially to build up a theoretical, technological and standard system which suits national conditions and lays a solid foundation for the overall development of direct-current power grid in future. By far, China falls short of a systematic research arrangement in the field. It is suggested that before the year 2020, the government should set up S&T projects or strategic priority research programs to support breakthroughs in basic theories and core technologies. After that, a major project on direct-current power grid technologies should be carried out under the leadership of China State Grid to form China's own direct-current power grid technologies and standard system.

(7) Health science based on systematic biology

Chronic diseases have become a major concern for population health in China. To enhance the monitoring and intervention of chronic diseases in their early stage and set up an effective prevention and treatment mode for early-stage diseases, it is important to study the dynamic molecular network and the network's dynamics and regulation of major chronic diseases in their evolution



process, to develop key blood-test technologies and combination technologies of multiple molecular markers from the perspective of systematic biology, and to work out new intervention techniques based on nutrition and lifestyle. At present, some arrangements have been laid out in China in the clinical diagnosis and treatment of chronic diseases, but the research into early stage diseases should become more systematic and early warning products and new intervention techniques should be identified.

(8) A simulation system of national survival environment

The complex structure and process of China's environmental systems (for instance, the climate, ecological and hydrological systems) has led to a number of outstanding problems, posing a threat to the nation's basic survival environment and holding back its economic and social development. Future research should focus on setting up an advanced numerical simulation system for regional survival environment in China and enabling the simulation and prediction of key elements concerning the survival environment. Meanwhile, a numerical simulation and forecasting system for typical ecological systems in China should be established and demonstrated to serve the macro-planning of the nation's economic and social development, disaster mitigation and prevention as well as public security. It is suggested that long-term support should be offered to such studies in the form of special science programs.

3. Major S&T issues requiring further deployment in fields and directions where the world might witness major scientific progress

(1) Jiangmen neutrino experiment

The success of the neutrino experiments at Daya Bay has crowned China as a world leader in neutrino research and will significantly contribute to decoding the puzzle of the disappearance of antimatter. In the Jiangmen neutrino experiment project, a large-scale and high-precision underground neutrino observatory will be built to observe neutrino oscillations in the reactor. In ten years of time, it will try to determine the mass order of three generations of neutrinos, measure neutrino mixing parameters up to 1% accuracy, and detect possible supernova neutrinos. It is suggested that the Jiangmen project be supported and constructed as a national major S&T infrastructures as soon as possible.

(2) Dark matter and dark energy

Astronomical observation can help investigate the basic properties of dark matter particles and determine cold and

warm dark matter models. With China's unique advantages in this regard, research should be focused on accelerating the assessment and construction of China's deep underground laboratories and conducting underground measurements of dark matter, so that the direct detection of dark matter can be achieved in a relatively short period of time. By carrying out space explorations in search of dark matter, scientists should look for possible signals for the annihilation of dark matter. Also, China should promote the construction of its dark universe survey telescope at Antarctica and its space telescope while actively participating in international ground- and space-based survey programs, and strive to determine the equation of state and pursue the nature of dark energy. Meanwhile, with the construction of large-scale scientific facilities, interdisciplinary and cross-institutional research should be encouraged to help China grow into a world-class competitor in the field.

(3) Big data platforms

Existing data processing theories and technologies cannot effectively cope with the exponentially growing size of scientific data nowadays. As a result, there is an urgent need to study the patterns of big data and develop platforms and tools for big data research. Studies should be conducted in the big data measurement and perception theories, the platform and system architecture for exponentially growing data processing, the analytical tools and development environment of data mining suited to different industries, as well as the research targeted at data's internal common properties. By setting up easily configured and reconfigurable experimental platforms to let data "have their say", and by analyzing the relationship between various data, researchers should strive to find new knowledge that are hard to obtain via other scientific paradigms, offer new insights into understanding the world, catalyze new scientific findings and technological innovations, and facilitate revolutionary changes in areas like the prediction and control of major natural disasters, the prevention and treatment of diseases and strategic planning and decision making.

(4) Main issues in brain and cognitive sciences

The study of brain mechanism for exploring the nature of intelligence and neural and mental healthiness is significant to the prevention and treatment of brain and socio-psychological diseases and the enhancement of public mental health. Scientific breakthroughs may occur in such aspects as the brain network's structural characteristics and functions, the impacts of functional activity of brain upon its structural connections, the self-organization mechanism, cognitive function evolution and optimal information

processing of the brain network, as well as the features of changes in the brain network's structure-function link under pathologic statuses. Interdisciplinary and cross-institutional research efforts should be strengthened from neurobiology, cognitive sciences, molecular genetics, computer science, information science to social sciences.

(5) “Artificial life” and synthetic biology

“Artificial life” and synthetic biology is likely to offer a brand new technical means to combat population aging, disease spectrum change, resources and environmental constraints and food security issues, and to revolutionize existing economic development modes. Research priorities include: using synthetic life systems to build human cell factory and produce high-value or new-energy chemicals, and promoting research on bioactive molecules to identify their biological and chemical mechanisms for elevating development and production efficiency; combining molecular module based breeding with synthetic biology to break technical bottlenecks in bio-energy transform (such as photosynthesis); and using synthetic biology technologies to set up cell models that better fit in human physiological properties and disease characteristics for the design of more efficient genetic and biological therapies. The research is expected to score a series of innovative results and promising, application-oriented new methods as well as new technologies. The new “materials” and “products” created may help China grow into a world-class rival in the domain. In addition to stronger protection and exploitation of intellectual property rights concerning synthetic biology, it is also important to study related bioethics and risk assessment.

(6) Mechanism of photosynthesis and “artificial chloroplasts”

By understanding the naturally occurring photosynthesis and developing relevant bionic technologies, researchers can invent an “artificial photosynthetic process” with

inorganic systems, and produce “solar fuels” from solar energy to achieve high-efficient water splitting and carbon dioxide reduction, which will exert a profound impact on global energy and resources patterns. Research focuses include the molecular mechanism and regulation principles of energy transformation in photosynthesis and biological solar cell technologies as well as the production of hydrogen and oil from algae and photosynthetic microorganisms. Major breakthroughs can lead to a 10-20% increase in the efficiency of solar energy utilization for energy plants and resource plants compared with that of today's agricultural crops, laying a foundation for the emergence of solar energy bio-transformation technologies. At present, the Chinese government has made certain arrangements in this field, but the deployment needs to be enhanced with an overall strategic planning.

(7) Sustainability of the Earth system on the Tibetan Plateau

The understanding of the Earth system processes of the Tibetan Plateau, widely recognized as the Third Pole of our planet, bears significant influences on the sustainability study of the future Earth as a whole. Research priorities include the impacts of deep geological processes and lithosphere deformation on Earth's surface layers, and the rules of interactions between the Earth's surface spheres, aiming at boosting the sustainable utilization of the mineral, water and environmental resources and ecosystem services in the region. New theories on the Plateau's uplift and metallogenic mechanisms and their environmental responses should be proposed to provide a basis for the scientific exploitation of the Third Pole and establish China's leading position in Third Pole research. At the moment, the government is supporting some of the major research in the field, but it still lacks systematic and comprehensive planning. It is suggested that the deployment be enhanced in the form of special S&T projects or strategic priority research programs.