# Possible Major S&T Breakthroughs in China over the Next Decade

China's major S&T breakthroughs are S&T innovations and progress with major influences on China's S&T and socioeconomic development, mainly comprising:

(1) Original innovation with significant contributions to world S&T advances, or pioneering major achievements in world S&T development standing the test of time, or solutions to major S&T problems generally recognized by S&T community, or those S&T achievements that open up new research directions and become international hotspots, for instance, synthetic crystalline bovine insulin, Goldbach Conjecture verification, theory of petroleum origin, and discovery of large oil and gas fields;

(2) Key technological breakthroughs to overcome high-tech barriers to trade; or those bringing about industrial leapfrog development in China; or contributing greatly to China's national security, living standards improvement; or boosting China's socioeconomic sustainability. Examples include satellite and nuclear weapons development, super hybrid rice, polybutadiene, and high-performance super computers;

(3) Transformative technology innovation opening new markets, creating new demand and forming new industries, such as Hou's Process for Soda Production and laser typesetting systems in the Chinese language. As a result of overall consideration, 19 major S&T breakthroughs are expected in China over the next five to 10 years.

In addition, China has already had a solid foundation for cutting-edge studies in some basic research areas, which are expected to give rise to new breakthroughs. For instance, a deeper understanding of universe in terms of dark matter, new particle discovery and surveys in the Milky Way; the discovery of new physical and chemical principles with practical values in the fields of high temperature superconducting, and topological insulators, quantum memory, quantum control, laser technology and mesoscopic science; progress in exploring life origins and new approaches to innovative thinking in the fields of synthetic biology and brain science; advances in various disciplines brought about by breakthroughs in mathematics and interdisciplinary studies.

## Major Breakthroughs Expected in Quantum Communication

Quantum communication, or quantum key distribution, is a new way of communication by encoding and transporting information in quantum states. Based on the principles of quantum mechanics, quantum keys are non-copyable and unconditionally secure. Once a key is stolen, the user will find out; as long as it is created, the encrypted information becomes unbreakable.

In 1984, C. H. Bennett from IBM and G. Brassard from the Université de Montréal jointly proposed the first quantum key distribution protocol – the BB84 Protocol, which marked the beginning of quantum cryptography communication. Besides, there are also the E91 Protocol proposed by A. K. Ekert from the University of Oxford in 1991, the B92 Protocol proposed by Charles H. Bennett in 1992, etc. These protocols are essentially consistent with the BB84 protocol. Today, quantum communication has become a research hotspot in quantum physics and information science and technology in the world, and is very likely to trigger a major revolution in the information industry.

### 1. Research progresses in quantum communication

In the past 30 years, the research and application of quantum communication have accomplished a number of remarkable breakthroughs across the world.

The world's first working demonstration of quantum cryptography was built by Charles H. Bennett, Gilles Brassard and their research team in 1989 with a 30-meter transmission distance. In 1993, based on the BB84 Protocol, scientists from the University of Geneva transmitted photon signals at 1.3 μm telecom wavelength in optical fibers over

1.1 km. In 1999, a 40 km quantum cryptography experiment was jointly conducted by Swedish and Japanese scientists. And after the successful operation of a 48 km quantum key system at Los Alamos National Laboratory for two years, in 2000, the system was applied to key distribution in free space over a distance of 1.6 km.

Since then, the distance and speed of quantum communication have been further improved. Some small-scale experimental quantum communication networks have been built, confirming the feasibility of networked quantum communication technology. Meanwhile, a roadmap for the implementation of wide-area quantum communication has been accepted worldwide: from using optical fibers to achieve citywide quantum communication networks, to using repeaters for connecting metropolitan area networks and establishing inter-city networks, to the ultimate realization of long-distance quantum communication in free space.

In 2003, researchers from the US National Institute of Standards and Technology and Boston University developed a type of detector that is capable of detecting single pulses of light. It provided the core technology in developing secure quantum communication and cryptography systems. In 2004, NEC in Japan claimed to have scored a new record of 150 km in quantum cryptography transmission distance. That same year, under the auspices of the Defense Advanced Research Projects Agency (DARPA) of the United States Department of Defense, the world's first quantum cryptography network was built by the Raytheon Company and Boston University beneath the streets of Cambridge, Massachusetts.

However, quantum key distribution schemes demand single-photon sources, which do not exist in real world conditions and are usually replaced by weak coherent light sources. Theories suggest that weak coherent light sources can lead to massive security loopholes. When channel loss reaches a certain level, invaders will be able to use Photon Number Splitting to get a full control of the key without being discovered. In fact, all quantum communication experiments before 2005 were just theoretical demonstrations, with real security distances no further than the order of magnitude of 10km, and the sifted key rate was extremely low.

In 2005, some Chinese scholars led by WANG Xiangbin and CHEN Kai proposed the decoy state solution to overcome the security loopholes caused by light source deficiency. With their solution, weak coherent light sources can help achieve quantum communication at security distance of over 100 km. In 2007, the decoy state quantum key distribution in optical fiber over 100 km was simultaneously implemented by PAN Jianwei's group at USTC and a joint research group from the Los Alamos National Laboratory and the US National Institute of Standards and Technology. This achievement unlocked the gateway to the practical application of quantum communication.

Later, a number of application oriented, small scale and fiber-optic quantum communication networks were built across the world. In 2008, based on the decoy state solution, PAN's team realized the world's first all-pass quantum communication network. In the same year, a joint experimental group in Vienna demonstrated a multi-node quantum communication network (the SECOQC network). In 2010, scientists from the Los Alamos National Laboratory started to secretly build a metropolitan area quantum communication network, which was not uncovered to the public until 2013. Also in 2010, through intercontinental cooperation, Japan's National Institute of Information and Communications Technology (NICT) inaugurated the construction of the Tokyo QKD Network in Tokyo.

As for the study of quantum repeaters, the world is still at the stage of fundamental research. The three key elements for the development of repeaters are: using quantum entanglement swapping to overcome the loss of photons; using quantum entanglement purification to overcome the degradation of the quality of quantum entanglement brought by decoherence; and using quantum storage to overcome exponential resource consumption caused by probabilistic events. The concept of quantum entanglement swapping was proposed in 1993 by Polish scientist M. Zukowski et al. and first put into practice by PAN Jianwei's team in 1998. The quantum entanglement purification scheme was put forward for the first time in 1996 by C. H. Bennett et al., but the scheme is difficult in implementation with existing technology.

In the year 2001, PAN Jianwei's group worked out a theoretical scheme to achieve quantum purification using existing technologies. They successfully implemented the scheme two years later, which experimentally proved that any unknown effect of decoherence in quantum information processing can be overcome. In 2008, for the very first time, his team demonstrated to the world the prototype of a quantum repeater. Quantum storage involves two core indicators: long storage life and high readout efficiency. According to the two indicators, the ideal physical system for quantum storage is a cold atomic ensemble. In 2007, Vladan Vuletić's team at MIT achieved quantum storage with up to 80% readout efficiency, which is the highest readout efficiency by far. However, the storage life was very short for only 200 nanoseconds. In 2010, Alex Kuzmich and colleagues from the Georgia Institute of Technology achieved storage life of 100 ms, the longest so far, but their readout efficiency was low at only 20%. In 2012 , PAN's team at USTC succeeded in quantum storage with 3 ms storage life and 70% readout efficiency, which is the best overall performance by far.

In free space quantum communication, in 2002, researchers from the University of Munich joined hands with scientists from some research institute under the British military to successfully transmit photon keys over 23.4 km between the Zugspitze peak and the Karwendel peak on the German-Austrian border. In 2005, PAN's team implemented free space distribution of quantum entanglement and quantum key distribution over a distance of 13 km in Dashushan Mountain in Hefei. In 2010, his team collaborated with researchers from Tsinghua University to set up a 16 km-long free space quantum channel between Badaling, Beijing and Huailai, Hebei. These experiments verified the possibility of photons breaking through the atmosphere and safely transmitting quantum keys via near-earth satellites to set up a global password transmission network. In 2007, Anton Zeilinger's team at the University of Vienna achieved quantum key distribution between two islands which are 144 km away from each other. In 2012, PAN and coworkers implemented two-way free space quantum key distribution with entangled photons over 100 km near Qinghai Lake, confirming the feasibility of free space quantum communication in a high-loss satellite-to-ground quantum channel.[1,2]

## 2. A new strategic focus across the world

The document *Quantum Information Processing and Communication: Strategic Report on Current Status, Visions and Goals for Research in Europe* published by the European Union spelt out Europe's development goals for quantum information in the next five to ten years. For example, it was going to focus on the development of quantum repeaters and satellite-based quantum communication, and strive to achieve quantum key distribution of the order of magnitude of 1,000 km. In September 2008, a business white paper on quantum cryptography was released in Europe, kicking off research on the standardization of quantum cryptography technology. Forty-one top research teams from 12 European countries including the UK, France, Germany, Italy, Austria and Spain jointly launched the Secure Communication based on Quantum Cryptography (SECOQC) project, which marked yet another large-scale international collaboration on major scientific issues after nuclear research (CERN) and space technology studies. Besides, the European Space Agency has initiated a long-distance quantum communication experiment to be implemented on the International Space Station (Quantum Entanglement for Space Experiments, Space-QUEST)[3].

Back at the end of the 20th century, the US government and scientific community already listed quantum information as a major research subject to support in their "American Competitiveness Initiative". In 2002, the US National Science Foundation invested 50 million dollars to support quantum communication research. In 2012, another four million dollars was earmarked for the "Interdisciplinary Faculty Program in Quantum Information Science", which aimed at supporting interdisciplinary studies related to quantum information and training and pooling interdisciplinary educators. *The White Paper on Information Science 2009* called on various research institutions in the US to coordinate and work with each other in quantum information technology studies. Meanwhile, the Advanced Research and Development Activity Program sponsored by the US Department of Defense planned to expand the application of quantum communication to satellite communication and metropolitan area and long-haul fiber-optic networks in 2014.

Japan has come up with a long-term research strategy on new-generation quantum information and communication technologies, aiming to build up an absolutely secure and confidential high-speed quantum information communication network in five to ten years' time and achieve a qualitative leap in the nation's communication technology. The Japanese Ministry of Posts and Telecommunications identified quantum communication a strategic research subject for the 21st century, to be studied with a mid- and long-term research goal over a 10-year span. The National Institute of Information and Communications Technology (NICT) of Japan also launched a long-term program to support quantum communication studies, which targeted at the implementation of quantum repeaters by 2020 and the construction of an extremely high capacity and unconditionally secure wide-area fiber and free-space quantum communication network by 2040.

## 3. Potentially wide applications in industry

With the rapid development of electronic information technology, microelectronic technology-based information technology will soon reach its physical limits. Meanwhile, quantum effects-based communication has been increasingly heralded as an important area to lead the future of science and technology. International giants in the information industry including IBM, Philips, AT & T, Bell Labs, HP, Siemens, NEC, Hitachi, Mitsubishi, NTT DoCoMo, etc. are investing massively in the research and development of quantum communication technologies to investigate and industrialize quantum communication technology.

Companies like Switzerland-based ID Quantique, US-based MagiQ Technologies and Australia-based QuintessenceLabs have already developed their quantum cryptography products. For example, ID Quantique's quantum cryptography products are now applied in many fields, including the installation of quantum encrypted lines for two private banks in Switzerland (Hyposwiss and NotenStein).

Quantum communication is useful not only in state-level secure communication such as national defense, but also in the complex operations of financial and government departments that involve the management of secret data and notes.

In the field of national defense, quantum communication can be used in the generation and distribution of keys to create a mobile, secure communication network in a combat zone. It can be used to improve the confidentiality of information transmission in optical networks, thereby enhancing the nation's information protection and information warfare capabilities. It can also be used in deep-sea communication, shedding light on new ways and new goals for oceanic and deep-sea secure communication and giving national defense a head start.

Quantum communication will play a huge role in almost all sectors, like for the anonymous communication of financial institutions, the monitoring of and communication support for power grids, gas pipelines, water supply networks and other important energy supply infrastructure[4], etc.

### 4. China's leading position in application-oriented quantum communication research

In China, the Ministry of Science and Technology, the National Natural Science Foundation of China, the Chinese Academy of Sciences and other departments have attached great importance and granted massive support to the basic and applied study of quantum communication. Recently, Chinese scientists have scored breakthroughs in application-oriented quantum communication and won a world-leading position in some aspects.

In 2004, GUO Guangcan's team from USTC successfully implemented the point-to-point quantum key distribution over 125 km in optical fiber between Beijing and Tianjin. In 2009, the team set up a "quantum network for government administration" consisting of six nodes in Wuhu City, central China's Anhui Province. However, it should be noted that these quantum key distribution lines couldn't stand photon-number splitting attacks.

In 2012, based on decoy-state quantum communication technology with a security distance of over 100 km and previous breakthroughs in quantum communication prototype devices and networking technologies, PAN Jianwei and his group completed the construction of the world's first large-scale metropolitan area quantum communication network, i.e. the metropolitan-area experiment and demonstration quantum communication network in Hefei. The network consists of 46 nodes and has found application in a number of government agencies, financial institutions and research institutions and universities in urban districts. In the same year, thanks to the well-developed, large-scale metropolitan area quantum communication network technologies, PAN's team built up the "quantum validation network for financial information security" in collaboration with Xinhua News Agency, applying quantum communication network technologies to the secure transmission of financial information for the first time in the world.

In 2013, the team's proposal to build a 1000 km-class fiber-optic quantum communication backbone network project was officially approved. Under PAN's leadership, a highly-reliable, scalable, civil-and-military-purpose wide area quantum communication network linking Beijing and Shanghai via Jinan, Hefei and many other cities will be constructed, and will become the world's first demonstrative platform for the validation, applied research and application of large-scale quantum communication technologies.

With regard to satellite-to-ground free-space quantum communication, thanks to a series of breakthroughs scored by PAN Jianwei and his coworkers, in late 2011, the Chinese Academy of Sciences inaugurated a strategic priority research program on quantum experiment satellite. According to plan, a quantum satellite will be launched around 2016 to achieve high speed quantum communication with the Earth, the first time ever in the world. It will also strive to connect ground-based fiber-optic networks and construct a preliminary wide-area quantum communication network across China[1, 5]. It is worth mentioning that Anton Zeilinger's team at the University of Vienna, a world-class powerhouse in quantum communication research, has offered to cooperate with China in satellite-to-ground free space quantum communication. Today, the Chinese Academy of Sciences has signed a cooperation agreement with the Austrian Academy of Sciences on the implementation of intercontinental quantum key distribution between Beijing and Vienna within the program's framework. In 2012, Professor PAN received the International Quantum Communication Award for "his pioneering achievements in the realization of quantum communication and multiphoton entanglement". It is the world's highest award in the field of quantum information, and PAN is the first Chinese to receive the award.

China's rise in quantum research laid a solid foundation for possible breakthroughs to occur in fundamental and application-oriented research of quantum communication in the country. Just as the *Nature* magazine commented when PAN's team was selected into "Features of the Year" in late 2012, it "will confirm China's ascent in the field, from a bit-player a little more than a decade ago to a global powerhouse."

### 5. Major breakthroughs to be expected in China

According to the roadmap for wide-area quantum communication technologies, major breakthroughs China may expect in the next ten years are as follows.

(1) In terms of fiber-optic quantum communication, the performance of key devices – single photon detectors will be significantly improved. These performance indicators include high operating frequency, low dark count rate and high detection efficiency. The development and production of some core devices, such as avalanche photodiodes (APD) for semiconductor single-photon detectors, will achieve complete localization in China. Meanwhile, large-scale networking technology will be further developed, and network capacity will stand at the order of magnitude of more than 1,000 users;

(2) In terms of cold atom-based quantum repeaters, within a few years' time, the life of quantum storage will hopefully reach 100 ms with readout efficiency exceeding 80%, so as to meet the demand for long-distance quantum communication;

(3) In terms of satellite-to-ground free space quantum communication, breakthroughs may occur in inter-satellite quantum communication, all-weather free-space quantum communication, satellite-borne quantum storage and other next-generation free space quantum communication technologies. Hopefully, the advances of these technologies will promote multi-satellite based global quantum communication, quantum communication in the daytime in free space, as well as the efficient global quantum entanglement distribution via inter-satellite quantum repeaters. At the same time, on the basis of a larger satellite-to-ground photon transmission platform, it is also expected that more progress will be made in the experimental validation of fundamental physics issues like nonlocality, relativistic effects and quantum gravity.

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# Major Breakthroughs Expected in Independent R&D of Basic Hardware and Software Platforms

### 1. Independently developed hardware and software platforms are of great significance to China

In February 2006, the State Council issued the *National Guideline on Medium- and Long-Term Program for Science and Technology Development (2006-2020)*, in which "core electronic devices, high-end universal chips and basic software" (i.e. basic software/hardware platforms) are included in the 16 major special programs[1]. Following that move, the Ministry of Science and Technology set out the *12th Five-Year Plan for Science and Technology Development*, calling for the independent research and development of central processing units (CPUs), operating systems (OS), software platforms, new intelligent mobile terminals, high-efficiency embedded CPUs, System-on-Chips (SOCs) and networking software as well as their industrialization and large-scale applications, so as to gradually establish a product system for independently developed core electronic devices[2]. This special program, to be completed in 2020, will receive approximately 32.8 billion yuan of funding from the central government and the total investment may exceed 100 billion yuan.

The three aspects of basic hardware and software platforms (core electronic devices, high-end universal chips and basic software products) are the commanding heights in international competition in the 21st century's electronic information industry. They are an important symbol of a powerful nation and are of vital importance to sharpening China's core competitiveness in the electronic information industry[3]. Meanwhile, the basic hardware and software platforms are closely related to the safeguarding and enhancement of national information security and people's living standards, and they play a huge supportive and integrative role in the development of information technology industry and related industries (such as energy industry and transportation). The advancement of these key technologies and products will not only produce new industrial opportunities but also create more social wealth.

## 2. R&D of hardware and software faces serious challenges

Basic software/hardware platforms are essential to a nation's information industry. As a latecomer in this field, China has witnessed in recent years a year-by-year rise in production value of the industry but relatively low profit margin, which was only 3.0% in 2009. The current market features a monopoly by international giants from other countries. In 2011, the total sales revenue of China's integrated circuit companies who were engaged in independent design and production was 10 billion US dollars, merely the increment of sales revenue of Intel Corporation in the same year[4].

Take high-end universal chips as an example. The data released by iSuppli (a market research firm in electronic manufacturing field) in December 2012 showed that in the global chip market of 2012, Intel enjoyed the highest market share of 15.7%, retaining its position as world's number one with total sales revenue of 47.22 billion US dollars. It was followed by Samsung (10.1%), Qualcomm (4.3%), Texas Instruments (4%) and Toshiba (3.6%)[5]. In May 2012, Intel revealed its roadmap for process technologies. According to the research and development pipeline espoused by the Intel's slides, 2015 will see the production of semiconductor components based on a 10nm process size, quickly followed by 7 nm and 5 nm parts[6]. At the same time, the global IC sector will move into the post-Moore era. The development roadmap of IC sector will no longer be certain and the product upgrading and replacement cycle is lengthened; the bulk silicon planar process will almost come to an end; three-dimensional devices will step up to the foreground, and other types of devices are also to join the competition; the process complexity will increase substantially, production line construction will require high investment, and the OBM's capacity for chip design is to gradually decrease; the R&D costs will continue to increase, but the manufacturing resources will gradually decrease; reducing the chip cost will no longer rely on the continued scaling down of the transistor; chip design and process will be closely combined again. However, China has not been well prepared to meet the challenges of the coming post-Moore era, and may lose the strategic opportunity again in the decade to come.

Take desktop operating systems as another example. The latest statistical data released by Net Applications (an authoritative market research firm) in August 2013 showed that among all desktop operating systems on the market in July that year, Windows held a market share of 91.56%, retaining its position as number one, and the market shares of MacOS and Linux were 7.19% and 1.25% respectively[7].

At the same time, many countries have been actively developing their own independent basic hardware and software platforms. For example, Russia had already developed a personal computer based on its domestic processor "Elbrus" and a super computer and communication system chip for aerospace application by 2012[8].

## 3. An industry system for the independent development of hardware and software must be established

The objective of developing basic hardware/software platforms is to overcome a group of technological difficulties and develop strategically-important core products including chips, software and electronic devices through sustaining innovation. By 2020, a high tech R&D and innovation system with international competitiveness will be generally formed in this field in China, and an internationalized high-level talent team will be built up to make significant contribution to helping China become an innovation-oriented country. By 2035, basic IT products and services based on China's own technologies will occupy more than 50% of its domestic market[9]. Although China has achieved some breakthroughs in the R&D of hardware and software, such as some CPU and OS products, the gap between our research and the world's mainly comes from China's lack of an industry system for the development of basic hardware and software. In this regard, an information industry system for China's independent hardware/software R&D must be established[10] and continuous improvement shall be made based on this technical system[4].

## 4. China's remarkable achievements in hardware and software development in recent years

With the support of National Science and Technology Major Projects, certain progresses have been made in the research and development of independent basic hardware/software products in China, and several small industry chains for independent platforms have basically come into being.

As for high-end universal chips, the Loongson 3B processor, an eight-core CPU independently developed by China, was successfully taped out in 2011 and has become a competitive core device in developing China's own high-performance computer[11].

In basic software, multiple types of operating system, office software, database and middleware have been successfully developed based on open source software (OSS) and found their application, including NeoKylin OS, Kingsoft WPS office software, ShenTong database, Kingbase database, Tongtech middleware and CS&S government affairs processing system, etc.

The field of core electronic devices has also seen breakthroughs. In August 2013, scientists from Fudan University developed a new basic microelectronic device of Semi-Floating-Gate Transistor (SFGT), a major breakthrough in the global cutting-edge integrated circuit technique innovation chain[12]. In July 2013, the programmable chip "COMET II" developed by the Institute of Electronics, CAS successfully completed in-orbit data processing for the "SJ-9A/B" satellite and became a high-grade programmable chip developed by China which, for the first time, rode on a satellite as a payload into space. It marked an important step toward the domestic production of core components for aerospace equipment in China[13].

Furthermore, an independent industry chain has basically emerged based on Sugon (such as server) and other products, and an effective cooperative mechanism has been built up with enterprises with independent intellectual property, including Loongson, NeoKylin operating system, Kingdee middleware, Tongtech middleware, Dameng database, YOZO Office and Kingsoft WPS.

In the next ten years, driven by informatization and system requirements and targeting at major products, China is expected to master key technologies to develop core electronic devices, high-end universal chips and operating system software for aerospace and new-generation equipment in information technology, nurture the comprehensive capability to independently design and produce those devices, chips and software products, so as to answer the national strategic and industrial needs, to overcome China's disadvantage in global information industry in terms of independency, controllability and supportability, and to produce internationally competitive products on our own.

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# Computing for the Masses Will Make Great Progress

Computer science and industry currently is facing many challenges, among which the most essential one is that the traditional computer industry is losing its development vigor. To reverse this trend, researchers have proposed a new perspective: a new paradigm named computing for the masses. Computing for the masses is much more than offering a cheap personal computer and Internet application to the low-income population, but means providing essential computing value for the masses (benefiting over 85% of the population), tailored to their individual needs[1, 2]. Computing for the masses has three features: augmented Value (V), Affordability (A) and Sustainability (S). It aims to break away from the conventional thinking of computer industry, fully excavate and meet the consumption demand of the masses for computing technology, and increase the science and technology supply of transformative innovation.

Computing for the masses needs to make computing enter the levels of business value for the masses' work and life. This means computing will gradually come into the human-cyber-physical ternary universe from cyberspace instead of being confined to computers and network hardware, software and services. At the same time, personalized big data computing will be carried out on the basis of cooperation by comprehensively utilizing the resources of human society (human)-cyberspace (cyber)-physical world (physical), with the technical supports of cloud computing, Internet of Things, mobile communication and photon information. It is the fundamental paradigm shift that must occur in computer science and industry during the realization of computing for the masses. Moreover, computing for the masses has to address scientific issues such as universal compute accounts, efficient sea-network-cloud platform, information ecosystem and national information accounts. From the perspective of computing industry, the "Insecta Classis Paradox" is the most critical problem to be solved in the realization process of computing for the masses and ternary computing. The Insecta Classis Paradox refers to a phenomenon as follows: on the one hand, massive users and terminals are supposed to bring a huge market; on the other hand, the users have personalized demands, thus there are no large volume applications that can be copied, neither can people think of one whose copy number can reach one billion or more. If there are no volume applications, there will not be low costs, and accordingly there will not be a huge market. Here comes the paradox. Ken Sakamura, a professor from the University of Tokyo, put forward a metaphorical explanation for such phenomenon: the traditional information systems are like the mammalia (of 5,000 species) and the Internet of Things systems are like the insecta (of five million species). How to deal with the Insecta Classis Paradox is a huge challenge for the future human-cyber-physical ternary computing system, and the possible development direction is specialized and personalized products and services that are reorganizable and easy to configure[2].

Computing for the masses is the development trend of computer science and industry in the next 30 years, through which China's computer market value is expected to reach 10 trillion yuan per year between 2040 and 2050[2]. The human-cyber-physical system will help information technology penetrate into substantial economy and social service activities, improve the intelligence level of people's work and life, and provide the masses with high-quality services in the aspects of medical treatment, geographic information, e-business, scientific research & education and films & recreation, etc. Meanwhile, traditional computer science will evolve into the human-cyber-physical ternary computing information science, traditional IT will be upgraded to sea-network-cloud information network technology, and new hardware, software, application modes, protocols and standards will emerge at the right moment[3].

Some scientific research, technology and application examples of human-cyber-physical system and computing for the masses have appeared. In 2011, the US National Science Foundation (NSF) sponsored a research on "Holistic Design Methodology for Automated Implementation of Human-in-the-Loop Cyber-Physical Systems". The project would develop an automated design framework of information physical system and enhance the interacted collaboration between humans and complicated systems composed of computing entity and physical entity with Brain-Computer Interface (BCI) and other technologies[4-6]. Researchers of the University of Illinois at Urbana-Champagne applied the human-cyber-physical system to the study of security applications[7]. Researchers from Imperial College London applied the human-cyber-physical system to the combination of sensing, communication and control in order to solve the difficulties in emergency management research[8, 9].

In 2009, China proposed a development strategy for its information technology called "Sensing China"[10], which aims to control the physical world by creating a universal information sensing system, promote the development of Internet of Things for "interconnection, interworking and information sharing", and help the application features of its information industry gradually evolve from human-cyber or physical-cyber integration into human-cyber-physical integration. In the same year, the Chinese Academy of Sciences (CAS) published the *Information Science and Technology in China: A Roadmap to 2050*, in which it was pointed out that developing universal information network is a major demand for economic and social growth and scientific research in China. The notion of human-cyber-physical ternary universe and information technology benefiting the masses was also proposed[11]. In 2012, CAS launched a new strategic priority research program named "Study on the New Generation Information Technologies for Sensing China". This project would create a new generation of IT systems that meets the human-cyber-physical ternary integration demand by developing transformative theoretical research and technological innovation to address the four fundamental challenges in today's information systems:

scalability of terminals, performance of mass data, energy consumption and data security[12]. As an important part of the program, the information system with the functions of interacting with humans, collaborating over the cloud and sensing the physical world will be studied with sea-cloud computing technology. To resolve the Insecta Classis Paradox, scientists from the Institute of Computing Technology of CAS put forward the notion of elastic processor[13]. Researches supported by the State High-Tech Development Plan, on themes such as "Smart Cities", "Intelligent Gateways for Internet of Things" and "Intelligent Home monitoring and management system" also reflect the R&D trends and application prospects of human-cyber-physical ternary integration and computing for the masses. Therefore, China may lead the world in the development mode of computing for the masses in the coming decade and embrace a promising future for its information industry.

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# Modular Design and Genome-wide Association Analysis Will Become Important Means of Molecular Breeding in Future

In recent years, with the rapid development of interdisciplinary studies such as molecular biology, genomics and systems biology, and with the breakthroughs in genome sequencing and other technologies, molecular marker-assisted selection and transgenic technology gradually became two important means of plant/animal breeding. Despite of the achievements, however, there are a number of problems in molecular breeding that need to be addressed immediately. As the major agronomic and economic traits of plants or animals are usually very complex and controlled by multiple genes, the modification of a single or several functional genes is inadequate for the overall improvement of the target's complex traits. Thus efficient, targeted and high-throughput techniques such as designer breeding by molecular module (DBMM) and genome-wide association study (GWAS) will become important means of molecular breeding in the future.

## 1. Technical implications of DBMM and GWAS

DBMM is a novel concept of breeding proposed on the basis of the modification of complex traits in agricultural organisms. This technique mainly involves the following three steps. (1) Exploration and functional interpretation of the molecular modules controlling complex traits. Explore the functionally important genes and their allelic variations which control complex traits in agricultural organisms, and interpret functional genes and module units capable of genetic manipulation in the regulatory networks. (2) Elucidation of the mechanisms of molecular module coupling. Use computational biology and synthetic biology to achieve a synergic and coherent coupling of molecular modules, analyze the integral regulation potential of module-module interactions on complex traits, and conduct theoretical modeling and functional prediction to achieve the coordination between molecular modules group, genetic background and regional environment. (3) Directional modification of complex traits through a genome-wide multi-module assembly optimization and an effective breeding scheme design[1].

GWAS is a high-throughput method to identify genetic variations that affect complex traits by analyzing the association between molecular markers and phenotypic variation with statistical tools[2, 3]. This technique usually uses molecular markers (mainly SNP) that are distributed throughout the genome as genetic variation. GWAS can significantly reduce the cost of whole-genome analysis with large sample sizes and thus accelerate research into the molecular breeding of plants and animals.

Breakthroughs in the DBMM technique will help interpret the genetic network of important traits and the molecular module control theory in animals and plants, identify molecular modules with high breeding value, and nurture genetic manipulation techniques for multi-module coupling, so as to solve the bottleneck problems in existing breeding techniques and ultimately achieve molecular breeding by designer approach for complex traits in animals and plants. The development of GWAS will contribute to the overall design of genome-wide genotyping methods with large sample sizes and low abundance of genetic materials, and allow an efficient identification of numerous modules associated with complex traits and exploration of allelic variations in plants and animals, so as to achieve the selection and utilization of elite germplasm resources in a broad range of agricultural species and ultimately the simultaneous combination of desirable traits in plant and animal varieties.

## 2. Scientific and economic impacts of the new breeding methods

DBMM is a novel and unique combination of cutting-edge technologies in life sciences with breeding practices. This technique will lead to a new direction through the revolution of breeding technologies by significantly improving the current breeding techniques, increasing agricultural yield and improving the quality of agricultural products. The GWAS technique not only generates molecular markers suitable for marker-assisted selection in plants and animals, but also provides important clues for exploring the molecular mechanisms of target traits. DBMM and GWAS will jointly promote the development of the emerging strategic industry of biological breeding in China, and play a key role in safeguarding national food security, enhancing integrated agricultural productivity, and sharpening the international competitiveness of China's agricultural products[4].

## 3. Research status in the world

The DBMM technique is now in an early stage of development. Studies on DBMM mainly focus on exploring important genes or QTLs and their allelic variations. Although DBMM technique is yet to be implemented, recent research results have shown the feature of modular control of complex traits. For example, the chromosome segment substitution 1BL/1RS has been introduced into wheat from rye, and the application of this natural breeding module has produced a large number of high-yield, disease-resistant wheat varieties. A gibel carp variety obtained through a dual mode of reproduction (gynogenesis and amphigenesis), dubbed "Zhongke 3", represents a new nucleocytoplasmic hybrid clone variety and hits an average yield increase by more than 20%[1]. Besides, a number of breeding simulation tools are increasingly developed and used.

The use of GWAS technique in animal and plant breeding mainly involves the mining of molecular markers and major functional genes that control complex traits. To date, several important molecular markers and regions have been identified in plants and animals[5, 6]. In plants, AFLP, SSR and SNP markers have been used for the GWAS of important agronomic traits in crops including corn, wheat, barley, soybean, and rice[7]. In animals, a large number of SNP markers have been developed for cow, pig, horse, and chicken; high-density chips are also produced and GWAS has been conducted for important economic traits and complex disease resistance[2].

## 4. China's advantages

The concept of DBMM was first proposed by geneticists from the Chinese Academy of Sciences in 2008. To date, the implementation scheme for an innovation system of DBMM has been worked out. Meanwhile, China has made a lot of remarkable progresses in the fundamental studies of DBMM and GWAS. Research on crop genomics in China is currently among world leaders, and the genome sequencing of a number of animal and plant species, including rice, wheat, cotton, carp, grass carp and goats have been completed. Development and application of new techniques in genomics have scored significant achievements, too. Genome-wide genotyping methods based on high-throughput genome sequencing have been developed, and GWAS has been successfully implemented for complex traits in rice, cow, pig, chicken, etc. A large number of animal and plant genes with application prospects have been cloned and functionally analyzed. A platform for the functional genomics research of rice has been built up in China, including a large mutant library, a full-length cDNA library and a microarray for genome-wide expression profiling. The construction of research platforms for “omics” including proteomics, metabolomics and phenomics are under way.

## 5. Possible breakthroughs in module breeding in the next ten years

In the next five to ten years, three major breakthroughs are likely to happen in the field of module breeding in China.

(1) “A compendium of molecular modules”, which refers to the genome-wide encoding law of complex traits in rice. By combining multiple genomics tools (e.g., genome sequencing and GWAS), the DBMM system can explore and identify the molecular regulatory networks controlling the high-yield, stable-production, good-quality and high-efficiency traits in rice, reveal the molecular mechanisms underlying complex traits, systematically interpret and obtain these molecular modules, determinate the biological effects of molecular modules in the same genetic background, clarify the corresponding genotype-phenotype correlation, and finally establish a network-based, open, and most authoritative database that is of guiding value for the breeding and genetic modification of rice as well as other cereals.

(2) A multi-module nonlinear coupling theory. According to the haplotype combination and molecular module components in natural populations, models are used to simulate and calculate the coupling effect of a series of molecular modules in the formation of the single complex traits and the interaction of multiple complex traits, so as to (a) identify the major and minor modules controlling single complex trait, (b) analyze the complex interactions (e.g., dominance, epistasis, synergism and antagonism) of major-major, major-minor, and minor-minor modules controlling single complex traits, and their determining roles in the formation of the traits, (c) assess the effect of module interactions on the robustness of systems-specific traits, and (d) analyze the interactive relationship of major and minor modules in the formation of different complex traits, clarify the dynamic effect of various modules on the formation of different complex traits as well as their control over the effect of major modules of complex traits on the formation of other traits, and reveal the molecular mechanisms of pleiotropic and multigenic effects, providing a theoretical basis for the modification of multiple complex traits in crops at the systems level. Then, multiple individuals with an identical genetic background and substitution of specific molecular module components (and module combinations) are screened out through populations of various genetic cross combinations (e.g., recombinant inbred lines, near-isogenic lines, and chromosome single segment substitution lines), the coupling effects of the above-mentioned molecular modules in the formation of single complex trait and the interaction of multiple complex traits are verified, the parameters and functions involved in model construction of multi-module coupling effect are adjusted, and a multi-module nonlinear coupling theory is eventually established through experimental validation.

(3) A genome-wide navigation system of DBMM. A genome-wide navigation system of breeding is specifically designed for solving the bottleneck problems of conventional breeding techniques. This approach enables the breeders to efficiently and selectively choose the most ideal haplotype-genotype from an enormous breeding population, which are eventually integrated into the desired elite varieties. For the first time, the genome-wide navigation system will conduct systematic description and the construction of the DBMM theory system, and help scientists obtain massive genomic information by scanning the existing genome database. A new breeding theory and technology can be built up using the combination of the obtained genomic information and cloud computing technology, which allows rapid and accurate prediction of individuals with multiple superior genotypes in a breeding population. Furthermore, this breeding technology enables efficient prediction of allelic combinations that are missing or need to be modified in elite varieties being cultivated in accordance with the breeders’ need, further providing an optimal strategy and scheme for the breeding of the most ideal varieties in specific growing regions.

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# China's Stem Cell Research is Expected to Become a World Leader

Capable of self-renewal and differentiation, stem cells have a great potential to be used in the study and treatment of human diseases, tissue and organ construction, reproduction and many other fields.

## 1. Current status and trends of stem cell research in the world

The tremendous application potential of stem cells has stimulated the enthusiasm of worldwide researchers. By August 2013, SCI had included 240,000 papers regarding stem cells, focusing on their acquisition and construction, regulation mechanism and applications, etc.

(1) Acquisition technologies of stem cells

Stable sources of stem cells and the establishment of stem cell lines are the basis of stem cell research. In addition to discovering and purifying adult stem cells in different tissues, scientists have been looking for a method to acquire embryonic stem cells (ESC). However, ethical issues make it difficult to get sufficient ESC for scientific research and clinical application. According to two studies in 2011[1] and 2013[2], cloning technology was used to clone ESC by reprogramming the somatic cells of adults via oocytes. These preliminary explorations pointed out a direction for ESC researches.

(2) Study on regulation mechanisms of stem cells

The regulation mechanisms of the self-renewal, pluripotency maintenance, dormancy and activation and differentiation of stem cells remain the focus of research at the moment. Scientists have made explorations from various perspectives including genes, proteins and epigenetic inheritance. Meanwhile, high-throughput technologies are used in the "extensive" research on regulatory networks and functional performance of stem cells. In 2011, the International Stem Cell Initiative constructed the world's largest genetic variation map of human ESC[3]. In the same year, from a genome wide perspective, Austrian and US scientists together drew a gene regulation network (GRN) map showing how neural stem cells maintain the balance between self-renewal and differentiation[4]. In November 2012, US scientists used transcriptomics technology to draw the first ontogeny profile of stem cells (HSCs)[5].

(3) Induced pluripotent stem cell (iPSC) technology

Since 2006, the induced pluripotent stem cells (iPSC) technology has become a hotspot in stem cell research. The technology's inventor, Japanese professor Shinya Yamanaka, won the Nobel Prize in 2012. In the past seven years, SCI has included nearly 3,000 iPSC-related papers, including approximately 900 published in 2012. Studies in recent years have revealed the mechanism causing low iPSC efficiency, and the impact of different inducing factor combinations (including non-genetic small molecules) on iPSC reprogramming has been explored based on certain genetic defects to optimize the iPSC technology and improve its security. In 2009, Chinese scientists confirmed for the first time that iPSC has the same developmental capacity as ESC. In 2012, US researchers mapped the molecular roadmap during iPSC reprogramming[6], laying a foundation for the future development of iPSC technology. In 2013, Chinese scientists successfully induced iPSC via small molecule compounds and obtained a normal mouse, which solved the security issue in iPSC technology applications.

(4) Trans-differentiation technology

The iPSC technology has also boosted the development of trans-differentiation technology. In recent years, researchers have been exploring the trans-differentiation mechanism and optimized the trans-differentiation technology, which facilitates the realization of trans-differentiation of somatic cells in lineages, inter-lineages, both in vitro and in vivo. In 2012, German researchers made a breakthrough by successfully trans-differentiating somatic cells into somatic stem cells[7]. US and Spanish scientists co-developed a new trans-differentiation technology called "indirect lineage conversion" (ILC) and induced somatic cells to a plastic intermediate state before differentiation[8]. This technology shortens or bypasses the whole reprogramming process for pluripotency, thereby it can reduce some drawbacks of the iPSC technology and provide a more universal technology than the trans-differentiation technology.

(5) Research on stem cell applications

The application of stem cells has increased with the deepening of basic research. Scientists have validated in the lab that somatic cells derived from various stem cells may function properly when repairing body injury. Meanwhile, a large number of clinical trials have been carried out. According to incomplete statistics, nearly 5,000 stem cell-based clinical trials have been performed worldwide, many with sound therapeutic effect. For example, the world's only approved clinical trial regarding embryonic stem cells reconfirmed its effect on visual acuity recovery in 2013[9].

Researchers have developed many iPSC-based stem cell models for a variety of diseases. The world's first clinical trial using iPSC therapy was approved by Japan for the treatment of age-related macular degeneration (AMD). Japan is also getting down to establishing an iPSC library to provide cells for iPSC therapy.

With regard to building tissues and organs with stem cells, a large number of tissues have been obtained worldwide for tissue engineering. In July 2013, Japanese scientists developed a new method to culture organ, where iPSC is utilized to build a functional three-dimensional liver, thereby providing a new path for the development of regenerative medicine[10].

## 2. China's research status and advantages

China's first SCI paper on stem cells was published in 1981, which is later than many other countries. However, the study of stem cells has been developing rapidly since then and by 2012, more than 3,000 papers were published by Chinese researchers every year, only next to the US in number. China has achieved a number of leading results in stem cell research, in areas such as regulatory mechanisms study, the iPSC and trans-differentiation technologies and application-oriented studies.

China enjoys a good foundation for the study of regulatory mechanisms on stem cells. Chinese scientists have explained the mechanism of 5-methylcytosine demethylation in ESC[11], explored the mechanism of early lineage specialization in mouse ESC[12], and revealed the lineage-specific regulatory pathway when pluripotent stem cells differentiate into neural cells[13].

Also, iPSC is one of China's research strengths. In 2007, China became the third country in the world to acquire the iPSC technology, following Japan and the US[14]. Later, it successively established an iPSC lineage for rhesus monkey[15] and rat[16]; obtained the world's first iPSC mouse by tetraploid blastocyst injection which validated iPSC pluripotency[17]; discovered that mesenchymal-epithelial transition was required for reprogramming of somatic cells[18]; found that vitamin C could significantly improve the reprogramming efficiency[19]; reprogrammed urine cells into iPSC to provide an "endless" iPSC source[20]; figured out the "barriers" during somatic cell reprogramming into iPSCs[21]; and replaced classic reprogramming genes with small-molecule compounds to reprogram the mouse somatic cells, making the long-anticipated technological breakthroughs come true[22]. These achievements won a favorable position for China in world's stem cell study.

China is also a world leader in stem cell trans-differentiation and has achieved a series of groundbreaking results. In May 2011, CAS researchers reprogrammed mouse fibroblasts directly into mature hepatocyte-like cells, marking a milestone in liver regeneration research[23]. In 2012, a research team from CAS reprogrammed urine cells directly into neural progenitor cells[24]. And in 2013, CAS researchers again used a 3D culture technique to trans-differentiate somatic cells directly into neural stem cells capable of proliferation and differentiation[25].

Besides, China has a unique advantage in building large animal models, with the support of national major research programs like the 973 Program which will hopefully boost China's development in the field and the realization of industrialization.

As for stem cell applications, China has carried out 165 stem cells clinical trials by far, focusing on the treatment of diabetes, liver diseases, etc. Three new medical technologies for tissue engineering and tissue-engineered cartilage transplantation have also achieved clinical transformation in 2010 to reduce the pain of many patients.

Meanwhile, regulations on the clinical application of stem cells issued recently in China will help with more healthy and orderly development in the field. With strong government support and research efforts, China is expected to become a world-leader in stem cell research in the future.


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# Biomedicine to Witness Leapfrog Development

## 1. The global pharmaceutical market has entered a new round of adjustment

The global pharmaceutical market keeps growing, but it faces problems like a decreasing ratio of R&D investment to new drug output and the expiration of patented drugs. It is shifting to emerging countries with an increasing proportion of biotech drugs, and a new round of adjustment has been kicked off.

Over the years, the pharmaceutical industry has been developing rapidly and persistently to become the fastest growing high-tech sector. However, the whole industry is facing a decreasing ratio of R&D investment to new drug output. The R&D spending of AstraZeneca, GlaxoSmithKline, Sanofi, Roche and Pfizer kept rising in the past 15 years but bore few fruits, and the output is significantly disproportional to the input. Besides, the expiration of a large number of patented drugs brings great opportunities to the generics market. In 2013, the world's top 20 pharmaceutical companies (in sales volume) had 35% patented drugs expired, including multinationals' "blockbuster" drugs①. From 2013 to 2018, drugs worth 230 billion US dollars may face patent expirations[1]. In this context, the emerging biotech drugs are more and more favored by large pharmaceutical companies. In 2012, eight biotech drugs ranked among the world's top 20 best-selling drugs, and it is expected that by 2018 biotech drugs will account for more than 1/4 of the total pharmaceutical sales revenue[2].

With the rapid growth of emerging countries and the structural transformation of the global pharmaceutical market, emerging countries and regions are expected to develop faster than developed countries in Europe and America which now still dominate the global pharmaceutical market. According to the IMS Health report, in 2016, developed countries will hold 57% of the global market share for medicine consumption, significantly reducing from 73% in 2006. Among them, the market share of the United States will fall from 41% in 2006 to 31% in 2016, and five European countries (the UK, France, Germany, Spain and Italy) from 19% to 13%. Japan will keep its share of about 10% during the period of time. By contrast, however, the market share of emerging countries will sharply increase from 14% in 2006 to 30% in 2016, with an annual growth rate of 12% to 15 % and market expansion of 150 to165 billion US dollars. Over the same period, the world's average annual growth rate will be between 3% and 6% and the US market will grow only by 1% to 4%[3].

## 2. The application of emerging biotechnology provides new development opportunities for the biomedical industry

The major breakthroughs in life sciences and biotechnology has brought biomedical research and industry into an era of revolution. For instance, translational medicine will fill the gap between basic research and clinical applications, accelerate technology transfer, and reduce the time and cost for drug research and development. Personalized treatment has emerged as a new treatment mode, for which the US Food and Drug Administration (FDA) has listed more than 100 personalized medicines[4]. Genome sequencing has entered clinical applications. In 2013, the first test-tube baby undergoing genome-wide screening was born. The genome sequencing technology was worth about two billion US dollars on the global market in 2012, which is expected to increase to 4.27 billion in 2017 with a compound annual growth rate of 16% from 2012 to 2017[5]. In the past decade, synthetic biology developed by leaps and bounds. Lots of major breakthroughs have attracted world-wide attention and will be used in drug development and disease treatment. Cell therapies, especially stem cell therapy,

① Source: IMS Market Prognosis Report.

are growing mature. Up to now, more than 5,000 stem cell clinical trials have been conducted worldwide, and five stem cell drugs have been approved to come into the market[②]. Gene therapy is gaining importance again. In 2012, the first gene therapy was approved by EU, while monoclonal antibodies were successfully applied to the treatment of cancer, autoimmune diseases, infectious diseases, allograft rejections, etc. and became the largest product category among biomedicines. So far, the FDA of US has authorized more than 30 monoclonal antibodies for the treatment of immunological diseases and various cancers. In addition, it approved the first therapeutic cancer vaccine, sipu-leucel-T in 2010, which is another important breakthrough made in recent years. Currently, more than 20 cancer vaccines are under development. The RNA interference (RNAi) therapy, which is a treatment method where specific gene expressions are controlled via silencing, took only 20 years to go from technological proposal to clinical application. At present, two RNAi targeted therapies have been approved by the FDA and the RNAi technology has been applied in 127 clinical trials.

The development and application of emerging technologies have brought new opportunities for the development of biomedical industry.

### 3. China’s opportunities for biomedical industry development

Issues like the expiration of patented drugs, the decreasing ratio of R&D investment to new drug output, the rapid market growth in emerging countries and the global pharmaceutical industry’s new round of adjustment are bringing good opportunities for the development of China’s biomedical industry. In China, the pharmaceutical market is expected to develop fast due to the rapidly growing market demand, strong government support, abundant social capital and the new medical reform.

(1) Favorable policies will boost the rapid development of China's biomedical sector

The Chinese government is enhancing its support for the bio-industry, including biomedicine. In 2006, the “development of major new drugs” and the “prevention and treatment of major infectious diseases including AIDS and viral hepatitis” were listed as state-level key research projects. During the *12th Five-Year Plan*, the former project will focus on the research and development of new drugs, the technological reform of drug varieties, the construction of an R&D platform for drug innovation, the establishment of an incubation base, the study on key technologies and international cooperation projects, with over six billion RMB worth of support in all[③]. Meanwhile, new vaccine adjuvant, therapeutic vaccines and recombinant clotting factor products are specifically have been proposed as the R&D focus for 2014. In June 2009, to speed up the development of bio-industry, the State Council issued *Some Policies for the Promotion of China’s Bio-industry*. In 2010, the State Council released *The Decision to Accelerate the Cultivation and Development of Strategic Emerging Industries*, in which the bio-industry including biomedicine were listed as one of the seven strategically important emerging industries. On July 9, 2012, the State Council issued *The 12th Five-Year Plan for the Development of Strategic Emerging Industries in China*, demanding that efforts shall be made to improve the research ability for biological medicine, to develop new drugs and accelerate the development of biomedical engineering technologies and products. On December 29, 2012, *The Development Plan for Bio-Industry* was released, emphasizing the high-quality development and enhancement of China’s bio-medical competitiveness. In addition, relevant departments also issued the*12th Five-Year Plan for the Development of Pharmaceutical Industry* and *The Special Development Plan for Medical Equipment Industry* to further clarify the specific objectives and tasks to be achieved in various fields, which provided a sound policy environment for the development of China’s bio-medical industry.

(2) China’s biomedical industry is quite vigorous

China’s bio-medical industry has been developing rapidly under the support of a series of policies, so has its bio-industry. In 2012, the biomedical output stood at 185.27 billion yuan. Lots of new biomedical products have emerged and dozens of genetically-engineered drugs and vaccines have entered the market, with hundreds of biotech drugs and vaccines put into clinical research. With the efficient synthesis of artemisinin, the world’s first recombinant hepatitis E vaccine came into the market, and the therapeutic vaccine for colorectal cancer, APDC, was approved for Phase III clinical studies. The Phase II clinical trials (252 cases) of targeting Aβ anti-Alzheimer’s oligosaccharides drug, which was developed by the Shanghai Institute of Materia Medica under the Chinese Academy of Sciences, were completed with preliminary results showing sound safety and effect. At the same time, a new anti-tumor drug, multitargeted tyrosine kinase inhibitor, Delitinib, has been approved for Phase I clinical studies in September 2012. In 2011, the first proprietary small-molecule antineoplastic,

② Source: US ClinicalTrials.gov database; statistics of clinical trials include ongoing and completed trails.

③ Source: July 17, 2013, the speech on 2013 Top 100 Pharmaceutical Companies Conference, delivered by MA Hongjian, the deputy director of the China National Center for Biotechnology Development, Ministry of Science and Technology.

Conmana (icotinib hydrochloride tablets), came into the market as a ground-breaking achievement in China's new drug development. On April 18, 2012, Di'ao Xinxuekang capsule developed by Chengdu Di'ao Pharmaceutical Group Co., Ltd. under CAS was approved by EU to enter the European market, the first therapeutic drug developed by China to appear in major developed countries. In March 2011, the Chinese Vaccine Regulatory System passed the assessment of the World Health Organization (WHO), indicating that China-made vaccines may hopefully come into the international market. In November 2012, under the official approval of WTO, the National Institute for the Control of Pharmaceutical and Biological Products of China became a WHO Collaborating Center for Standardization and Evaluation of Biological Products, which will strive to provide strong technical support to Chinese drug manufacturers and help them become suppliers of WTO.

With the rapid development of biomedical industry and the vigorous growth of emerging technologies under government support, China is expected to achieve leapfrog development in a new round of international pharmaceutical adjustment.

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# China's Industrial Biomanufacturing Technology to Reach World Advanced Level

## 1. Industrial biomanufacturing is an important part of bioeconomy development

Biomanufacturing is a new industry for large-scale material processing and transformation via biological function to provide industrial goods for social development. It uses microbial cells or enzyme proteins to catalyze chemical synthesis and biomass feedstock to synthesize energy chemicals and materials in order to produce energy and chemicals as a replacement for the petrochemical industry route[1]. Based on the latest development in life sciences, it mass-produces the needed energy and chemicals in an advanced, highly efficient and environmentally-friendly way through the combination of biological and manufacturing technologies, with design and improvement of modified organisms as the core.

Currently, through the advanced biomanufacturing process, many materials can be produced such as basic chemicals, pharmaceutical intermediates, amino acids, vitamins, polymer materials and dyes, and the chemical production process of chemical intermediates and higher value chemicals can be renovated. Meanwhile, industrial enzymes obtained through such bio-manufacturing process can be used in bio-coloring, bio-bleaching, bio-tanning and bio-degumming, etc., which can effectively promote the upgrading of textile, paper-making, leather, and chemical processes in an environmentally-friendly way. Therefore, the development of industrial bio-manufacturing can help combat the severe challenges of resource constraints, energy shortage and environmental degradation, which is of important strategic significance for building a low-carbon, green and sustainable economic system.

At present, modern biotechnology is gradually going toward large-scale industrialization, and the global bioeconomy is in a transition period toward rapid development. The fast growing bio-manufacturing industry has become the focus of modern biological technology and industry.

Major countries and regions in the world have given priorities to bio-manufacturing in their biological economy strategies. For instance, the *Innovating for Sustainable Growth: A Bioeconomy for Europe* released by EU in February 2012[2] proposed for an increased investment in the research and development of bio-based products market. The Obama Administration released the *National*

*Bioeconomy Blueprint* in April 2012[3], which called for concrete actions to promote biotechnology research and innovation in order to respond to challenges in health, food, energy and environment sectors. In November 2011, the Ministry of Science and Technology of China released the *12th Five-Year Plan for Modern Bio-Manufacturing Technology Development*[4], demanding the nation to meet its overall objective of setting up a modern bio-manufacturing innovation system by 2015. The State Council printed and distributed *Bio-industry Development Plan*[5] in December 2012, putting the enhancement of the economic efficiency of products and the large-scale development of bio-manufacturing industry as major tasks for the development of bio-industry in China.

## 2. Modern biotechnology promotes the formation and development of bio-manufacturing innovation system

The rapid development of basic biological research makes technical barriers less formidable as they were. The advances in DNA sequencing, the leapfrog development of proteomics and the breakthroughs in synthetic biology are leading biology toward unprecedented advancement and promoting the formation and development of industrial biomanufacturing systems.

With the development of genomics, systematic biology and synthetic biology studies, more artificially synthetic biosystems have enabled the green and efficient biomanufacturing of a variety of compounds. With the progress of engineering technologies of biological process such as bio-refining, bio-catalysis, bio-processing and modern fermentation, the biomanufacturing technology will be able to render stronger support to the industry.

The alternative biomass feedstock as a replacement for petrochemical raw materials and the alternative biological route for chemical processes are the key research directions in international industrial biotechnology research. In recent years, genetic recombination of microorganisms, synthetic biological assembly and systematic biotechnology optimization have been the new hotspots in biotechnology, which form the biochemical synthetic path of petrochemical products. The biomanufacturing of traditional petrochemical products such as 1,3-propanediol, 3-hydroxypropionic acid, butanedioic acid, isoprenoids, 1,4-butanediol, iso-amyl alcohol and crylic acid has obtained or is about to obtain a competitive advantage over the petroleum route. Global bio-based materials technologies have witnessed continuous innovation. The industrial application of bio-plastics and biochemical fiber has been achieved and bio-based rubber tires have emerged. Biocatalyst-based green catalysis technology continues to make progress, which has been applied in the synthesis of active pharmaceutical ingredients and their intermediates, agricultural chemicals and their intermediates, cosmetics and its intermediates as well as other fine chemical products, which kept yielding typical success cases on energy saving and emission reduction.

According to the Organization for Economic Cooperation and Development (OECD), the proportion of bio-based chemicals and other industrial products (excluding biopharmaceutical products) in all chemical production is likely to increase from 1.8% in 2005 to 12%–20% in 2015 and 35% in 2030[6]. A World Economic Forum (WEF) report predicted that by 2020, the technologies for the conversion of biomass to fuels, energy and chemicals will bring economic benefit up to 230 billion US dollars to the world[7].

## 3. China faces good opportunities for the rapid development of industrial biomanufacturing

Industrial fermentation is one of China's traditional strengths. In recent years, China has formed a general pattern for its biomanufacturing industry, and a market-oriented, enterprise-led, industry-university-research combined and upstream-to-downstream industrial biomanufacturing system is taking shape. Chinese researchers continued to make breakthroughs in terms of the originality of artificial cell factory construction and other areas. A large number of bulk fermentation products have significantly sharpened their international competitiveness and created huge economic and environmental benefits. Meanwhile, clean and efficient biological processes have been developed for the production of chemical active pharmaceutical ingredients and their intermediates, whose effects in energy conservation, water conservation, toxicity reduction and waste water discharge are significant while product quality is improved.

China has advantages in the mass production of traditional fermented products and bulk fermented products such as amino acids and vitamins, with technical strength to produce fine chemicals through biological methods. In terms of bioenergy, the biofuels which are converted from non-grain crops are under development and the utilization of microalgae feedstock is a main direction in biodiesel development.

In bio-based materials, China has the capacity of producing 5,000 tons of polylactic acid (PLA) (ranking the second in the world), 10,000 tons of poly (butylene succinate) (PBS), 10,000 tons of poly (propylene carbonate) (PPC) (ranking the first in the world) and over 20,000 tons of starch-based materials annually, which made China the only country to be able to produce a variety of long carbon chain dicarboxylic acids on a large industrial scale through microbial fermentation technology. The country's annual production capacity of polyhydroxyalkanoates (PHA) is more than 18,000 tons, which leads the world in both industrialized product types and production. Besides, the world's first facility for preparing polyvinyl alcohol (PVA) preparation with biomass was built in 2012 in China.

Currently, the development of industrial biomanufacturing is injecting new vitality into global economic growth and accelerating the sustainable development of modern industries. China faces new opportunities in the field of industrial biotechnology. On the one hand, the merge and integration of life sciences and biotechnology are expected to bring about new scientific breakthroughs. By strengthening the study of emerging disciplines such as synthetic biology and their technological innovation will improve China's core competitiveness in advanced industrial biomanufacturing.

On the other hand, the establishment of a chained industrial technology innovation system will promote the transformation of major technologies, and help shape modern biotechnology that is based on highly efficient bio-catalysts and their industrial application, which will effectively promote the upgrade of China's high-tech industry and the transformation of economic development mode.

### 4. Breakthroughs to be expected in China in the next 10 years

In the next 10 years, focusing on the major demand of sustainable industrial development, China is expected to achieve new breakthroughs in the study of the structure and function of enzyme proteins and biocatalysts, microbial metabolism and synthetic biology, and principles and rules study of complex biological processes. It is expected that via breakthroughs in functional genomics, calculation design, chemical synthesis and system optimization, China will be able to build new synthetic organisms with international impacts to achieve the highly efficient conversion and utilization of renewable biomass resources like sugar, non-grain biomass and organic waste and even industrial emissions (carbon monoxide, carbon dioxide), shift the existing production mode of functional materials, industrial chemicals and pharmaceuticals synthesis, and substantially increase the production level of biological products so as to create a series of energy and chemical products that are economically viable and competitive over petroleum-based products, and therefore to establish a world leading industrial biomanufacturing technology system[8].

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# Major Breakthrough May Be Made in Ubiquitous Manufacturing Information Perception and Networking Technology

### 1. Scientific connotation and significance

The ubiquitous information manufacturing technology is a comprehensive and integrated information processing technology based on ubiquitous networks. Centering on ubiquitous perception, it aims to provide ubiquitous services via the expansion and enhancement of ubiquitous intelligence. A manufacturing-oriented ubiquitous network is the integration of an industrial field-level sensor network, an RFID network for logistic management, a plant control network and an enterprise information internet. Ubiquitous perception, which uses microsystems and electronic devices as well as systems embedded in application environments to capture, analyze and transfer multi-type information, will offer human a brand new technical method to gain a deeper understanding of our physical world, to greatly expand our knowledge and detection ability about that physical world, and to promote more reasonable and finer control of industrial production activities in all fields[1].

The ubiquitous information technology will bear a profound impact on manufacturing technologies and the manufacturing industry for a fairly long period of time, especially with its immeasurable influences in aspects like ultra-precision machining and manufacturing under extreme conditions. The development of informative manufacturing system technology based on ubiquitous perception will not only make equipment much more user friendly, but thanks to their self-calibrating, self-diagnosing and self-repairing abilities, they will also lead to a human-machine coordination manufacturing system with human as the main decision-maker. Supported by abundant information, it can improve the effectiveness of production organization and allocation, increase equipment utilization rate, and boost the production efficiency of the manufacturing industry. Meanwhile, with a substantial elevation of equipment intelligence, the patterns and methods of manufacturing are no longer confined to meeting the user's demands in a passive way, but to actively detect changes in the user scenario and launch information interaction for analyzing and finally serving the user's personal needs[1].

## 2. Major progresses in the world

In the field of ultra-large micro-sensor networking, the single-hop star network remains as the most reliable network topological form used in plants. Meanwhile, the multi-hop Mesh structure began to come into the spotlight for research on the wireless sensor network topological structure in plants.

As for the integration of plant wireless sensor network and RFID, the merging has just started. At present, there are three ways of merging: the RFID reader with the wireless sensor network node, the RFID label with the wireless sensor network node, and RFID with wireless sensor network at the system level[2].

As for plant control over wireless networks, the low-power short-range wireless technology represented by IEEE802.15.4 and the wireless LAN technology represented by IEEE802.11 began to serve as field equipment-level and workshop-level networks. The WiMax technology has been applied to the construction of enterprise-level long-range data exchange networks, and Cisco and Intel have released their relevant products.

In low-cost wireless positioning and tracking technology, besides the GPS system, other technologies such as Wifi, Zigbee, Bluetooth, Ultra Wideband and RFID real-time positioning and tracking technology have gradually found application in plants. Current research efforts focus on reducing the cost of precise ranging technology and improving its precision and real-time performance.

In its merging with the Internet, the current plant wireless monitoring and control network goes no further than the intranet connection with the plant ERP system. As the built-in IPv6 network technology is becoming a research hotspot, an Internet engineering task force is now setting standards to address problems concerning long-distance access to plant equipment information and sensing information[1].

Thanks to the advancement of these technologies, German and American governments and companies have recently put forward a number of innovative strategies and plans for their manufacturing industry based on equipment interconnection and manufacturing services.

## 3. Advantages of China

The Chinese government attaches great importance to the development of the IOT (Internet of Things) technology, which involves the ubiquitous perception network technology. With the support of state-level scientific research funds such as "973" and "863", China has launched major programs on sensor networks and IOT with ever increasing investments[3]. In national strategic plans such as *The National Medium- and Long-Term Program for Science and Technology Development (2006-2020)*[4] and *The 12$^{th}$ Five-Year Development Plan for National Strategic Emerging Industries (2011-2015)*[5], the IOT and related perception and networking technologies are listed as a strategic industry and development priority, to which great fund support is promised. In 2013, the Ministry of Industry and Information Technology earmarked 500 million RMB for the R&D of IOT in China[6], and the central government approved the proposal to set up a national sensor network innovation and demonstration zone in the city of Wuxi[7]. Many Chinese cities have started their IOT industry planning and initiated related research programs. With such great support from the government, China has achieved many breakthroughs in IOT-related areas and has built up several large-scale and mature application-oriented demonstration systems. Besides, as one of the world's leading countries in the standardization of sensor network technologies, China owns a large number of patents in this area and a complete chain of the wireless intelligent sensor network industry, along with high coverage rate wireless telecommunication networks and broadband networks, which has laid a solid foundation in infrastructure for China's development of the ubiquitous manufacturing perception network[8].

CAS is one of the first research institutes in China to be engaged in wireless sensor network studies. Back in 1999, the Academy listed such study as a key project in its Knowledge Innovation Program. During the 10th and the 11th "Five-Year Plan" periods, hundreds of millions of RMB was poured into tackling technical difficulties and developing prototypes for sensor network technologies by CAS institutes like the Shanghai Institute of Microsystem and Information Technology, the Shenyang Institute of Automation and the Institute of Microelectronics. In 2010, CAS inaugurated the IOT Research and Development Center to lead the Academy's research, development and application missions in IOT and intelligent sensor products. Under CAS' leadership, several innovation system frameworks for sensor networks with Chinese characteristics have been established across China and accepted by national and international standards[9]. CAS institutions including the Shenyang Institute of Automation, the Institute of Information Engineering and the Shanghai Institute of Microsystem and Information Technology have already laid out preliminary deployments for the R&D of equipment interconnection, network interconnection and information safety issues in the industrial sector.

## 4. Major goals to achieve in the future

Centering on information acquisition and interaction in the manufacturing process, China shall strive to solve two core scientific issues in the future: the interconnection and information transfer between ubiquitous ultra-large-scale sensor nodes, and the information flow integration within enterprises and long-range access.

As for the interconnection and information transfer between ultra-large-scale sensor nodes, the restrictions in topological structure will be technically removed to achieve the rapid dynamic networking of micro-sensors using the same telecommunication media, the dynamic maintenance of the network, and the demand-based access to different networks. Breakthroughs will be made in the middleware technology for the integration of the wireless sensor network and the RFID network to realize mutual operation between them. Core equipment for integrating RFID reading function with wireless sensing and networking function will be developed.

As for the information flow integration within enterprises and long-range access, breakthroughs are expected in developing highly reliable and real-time wireless network technologies for factory automation and enterprise-level long-range wireless network technologies, which will realize the interconnection and mutual operation between the wireless network and the wired control network. Breakthroughs are also to be made in the precise wireless ranging technology to promote the ranging sensor's precision and reduce its cost. Complete acquisition of process data and product quality information is going to lay a foundation for the optimization of control strategies. By acquiring information about the health condition and operation efficiency of machines and the positioning of plant assets at any time needed, the elaborate management of enterprises will be realized.

These achievements as predicted to take place in the future will in turn trigger a transformation in the manufacturing industry's management mode from today's centralized management and control to distributed control, and from partial or local optimization and control to trans-regional, overall optimization and decision-making.

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# The Field of Advanced Materials May See Innovative Breakthroughs and Overall Enhancement

## 1. Scientific connotation and significance

Advanced materials technology is one of the most important technologies impacting modern social and economic development. Its advancement will enrich the technological element in related products, shorten production cycle, and promote the emergence and prosperity of high-tech industries. Moreover, it will significantly change a nation's industrial structure, help create personalized lifestyle and life concept for the people, and even influence international political situation.

Take lightweight materials as an example. The realization of lightweight modern transport relies on lightweight aluminum/magnesium/titanium alloys and carbon fiber composite materials. It is estimated that a vehicle may reduce 20% of its weight if made of lightweight materials. Data show that a 10% decrease in the weight of a car body can reduce its fuel consumption by 6% to 8%, increase its efficiency by 5.5% and cut the noise by 2 dB[1]. Lightweight materials may become one of the most important means to solve oil resources shortage and global warming, and make a significant contribution to global sustainable development.

## 2. Recent progresses in the world

In the 21st century, many countries in the world, especially developed countries, have taken the development of advanced materials as a major driving force behind industrial progress, economic development and national security. The global trends in this regard include more emphasis on basic research, stronger R&D funding, more intensive R&D expenditures in strategic priority areas, enhanced policy support, as well as the remarkable role of enterprises in innovation.

In the United States, biomaterials, information materials, nanomaterials, extreme environment materials and material computational science are listed as major frontier research directions, to support the development of related science and technology and meet the needs of national defense, energy supply, electronics and other sectors.

In Japan, the research and development of materials that can coordinate resources with environment and those with low environmental pollution risks and high reusability are identified as primary evaluation indicators in its 21st century advanced materials development plan. And as a result, a series of development initiatives have been issued.

Among the ten development priorities of the Seventh Framework Programme (FP7) of the European Union, quite a few are related to advanced materials. EU remains a global leader in fields like graphene, aerospace materials, metamaterials and superconducting materials, and its member states have laid out their own development action plans on advanced materials[2].

## 3. Advantages of China

(1) In high performance steel

Iron and steel output is a symbol of a country's industrialization level and national defense strength. As a major producer and consumer of steel, China has been world's biggest producer of crude steel for 16 consecutive years. By implementing a series of projects, China has scored significant progress in the basic research of steel. For instance, it has worked out and put into mass production a kind of world leading super steel, which can exponentially increase the strength of low carbon steel, low alloy steel and structural alloy steel by adjusting process without changing the composition.

(2) In key materials for large-scale construction projects

Materials for high-speed railways have been developed rapidly in China with government support on major programs such as the National Key Technology R&D Program on the key materials and component reliability of high-speed train. Localized research has seen significant progress from special materials production to supporting materials supply.

Nuclear industry offers an opportunity for the localization of domestic nuclear-related materials, which is a prerequisite foundation for China to achieve independent development of nuclear powers. Many research institutions have been attracted to and got involved in this research area.

In recent years, China developed view-cast techniques, fulfilled the localization tasks of large cast steel back-up roll, marine crank, runner casting for hydraulic turbine in the Three Gorges Project, and heavy forging in nuclear plants. These achievements guaranteed China's self-supply of large castings and forgings, and improved the quality of large steel-ingot.

China has also developed a novel-type aluminum alloy featuring high strength, high ductility and low quenching sensitivity, whose main components patent has been approved by the WIPO and formally announced.

(3) In superconducting and nano-twinned metals

China has a good foundation in superconductivity research. Especially, scientists from the CAS Institute of Physics have published more than 400 papers on iron-based superconducting with over 14,000 citations[3]. In 2012, by optimizing preparation technology, the Institute of Electrical Engineering has achieved current carrying capability of 17,000 A/cm$^2$ at 10 T, a world record that suggests a promising future for iron-based superconductors in practical applications[4].

Nano-twinned copper was discovered by scientists from the CAS Institute of Metal Research in 2004. Its extreme strength and ultra-high work hardening effect was revealed in 2009. Today, the study on nano-twin structure and nano-twinned materials has become a hotspot in the world. The work has led the development of global nanomaterials research and promoted the R&D of advanced materials and technologies[5].

## 4. Goals to be achieved in the future

Iron and steel, as representatives of basic raw materials, are fundamental, leading and pivotal components of the modern high-tech industry. It is expected that by the end of the *12th Five-Year Plan (2011–2015)*, high strength and high toughness automobile steel and silicon steel sheet, which China used to rely heavily on import, will see large-scale domestic production with over 90% Chinese market share. The self-sufficiency rate of marine corrosion resistant steel, low-temperature pressure vessel plate, wheel and axle steel for high-speed railway and high pressure boiler tube will reach 80%. Meanwhile, the proportion of high-strength rebars (400 MPa and above) will exceed 80%[6].

Key materials for state-level construction projects will gradually come to self-sufficiency, and China's own standards will be formed. For example, the standard for the purchase and supply of key materials for high-speed railway would shift step by step from the existing European and Japanese standards to Chinese standards, and a number of key components products with independent intellectual property rights will be developed and industrialized[7]. As for key materials in the nuclear sector, with the completion of China's fourth AP1000 nuclear power plant units, the nation's localization level of third-generation nuclear power equipment and related key materials will exceed 80%[8]. As for critical materials for large aircrafts, high performance light alloys and composite materials will be produced more and more domestically with both performance improvement and cost reduction.

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# Clean and Comprehensive Utilization of Coal Resources Will Become an Emerging Industry

## 1. The future of coal utilization

Among all traditional fossil energies, coal accounts for 30% of the world's total energy demand and 40% of its power generating capacity. Coal is the only energy resource in which China maintains a reserves advantage, and it accounts for approximately 70% of the nation's non-renewable energy consumption. From now on to the foreseeable future, coal will remain to be the major energy source in China and the rest of the world. However, direct coal combustion suffers from low energy efficiency (only around 40%), and the serious pollution and $CO_2$ emission rising from coal mining and combustion severely endanger human health, our eco-environment and global climate. Meanwhile, low grade coal, which features high volatile content, high water and oxygen content, high spontaneous combustion risks and low heat value, accounts for a very large proportion in China's coal reserves and output, 46% to be exact, comprising 13% of brown coal and 33% of low metamorphic bituminous coal[1]. Therefore, the efficient and clean utilization of coal is an inevitable choice for China to solve its resource and environmental issues in energy production and consumption where coal plays the major role.

Therefore, we should spare no effort to boost the research and development of clean coal technologies, including coal mining, washing, gasification, composition and refining, purification and separation, combustion and power generation as well as emission control. The high-value utilization technology for oil and gas production through coal pyrolysis, the core liquefaction technology for graded chemicals production with low grade coal, and the advanced industrial technology for large-scale coal gasification shall be leveraged to achieve the cascade utilization of coal resources, and to forge coal-associated power, liquefied fuel, chemical, heating and synthetic gas industries. By doing so, we will be able to substantially improve energy utilization efficiency and environmental quality, greatly reduce coal and water consumption and $CO_2$ emission, and push forward the optimization of China's energy and economic structures to safeguard national energy security.

## 2. Progress in clean and efficient utilization of coal in the world

Since the end of the 20th century, many nations have proposed their clean coal technology development plans to promote the R&D and commercial application of coal combustion technologies in their countries. The United States has implemented five rounds of "clean coal technology (CCT) development planning" since 1985[2]. It launched a research program on 700°C ultra supercritical unit in 2001 and the FutureGen project in 2003, and has been accelerating the research, development and demonstration of innovative clean coal technologies since 2005, including the application of carbon capture and storage at coal power plants and the development of IGFC-CC and other new technologies[3].

In Europe, the Austenic steel USC units were developed and applied in the 1980s, and demonstrative 700°C USC power plants were established with the support of AD700 Plan (1998-2014). In 2004, EU kicked off the Hypogen program under its FP6, aiming to develop demonstrative 400 MW IGCC power plants for power generation, hydrogen production and $CO_2$ capture and storage based on coal gasification[4, 5].

In Japan, the development of clean coal power generation focuses on USC, IGCC, IGFC and $CO_2$ capture and storage technologies, and a nine-year (2008-2016) development plan for 700°C USC power generation technology and equipment was launched, aiming to achieve 35MPa/700°C/720°C product development in 2015 and 750°C/700°C product development in 2020[6, 7].

Australia launched its COAL21 Plan in 2004. The plan focuses on power generation, hydrogen production, synthetic gas production and $CO_2$ separation and processing systems based on coal gasification[8].

In Canada's *2020 Clean Coal Technology Roadmap*, the four research priorities and implementation goals include upstream coal dressing, combustion, oxygen-rich combustion, and gasification and chemical synthesis. Canada also proposed a plan called ZECA to develop advanced technologies for hydrogen production with coal and for $CO_2$ capture, separation and storage[9].

In today's world, USC units are developing toward higher parameters (35 MPa, 700°C), and gas turbines are developing toward higher initial temperature (1,500°C). The clean and efficient power generation technologies have been developing rapidly, including IGCC and poly-generation based on coal gasification and the coal gasification-fuel cell-fuel gas-steam combined cycle. In terms of processing and transformation, coal gasification technologies are going toward a large-scale, high-adaptability, low-pollution and easy-to-purify future. In terms of environmental protection and emission reduction, technologies for dust removal, desulfurization, denitration and $CO_2$ capture, utilization and storage are becoming more diverse and integrated.

## 3. Progress in the clean and efficient utilization of coal in China

In China, clean coal technologies are regarded as a strategic solution to adjusting coal industry structure, elevating the value of coal and its products, protecting the environment, and achieving the sustainable development of the energy industry. The *National Medium and Long Term Program for S&T Development (2006-2020)* takes the clean and efficient use of coal as a priority in the energy sector, including "the clean and efficient utilization, liquefaction and poly-generation of coal", "the research and development of high parameter USC units, USC circulating fluidized bed and similar high-performance power generation technologies and equipment, …, and technologies and equipment for coal pollution control and utilization". The *12th Five-year Plan for National Economic and Social Development* also pointed out the necessity to "push forward the development of clean and diverse energies, and develop clean, efficient, large-capacity coal units", to "control greenhouse gas emissions and promote the treatment of $SO_2$ and $NO_x$ from thermal power industry".

In its *12th Five-Year Plan for Energy Technologies*, China proposed to develop large-scale, advanced gasification technologies suitable for China's coal types. It called for breakthroughs in the 8.7 MPa large-scale, high-pressure water coal slurry gasification technology, the 4.0 MPa large-scale dry coal powder gasification technology (waste boiler or quench), the high-pressure dry coal powder gasification technology (6.5 MPa), the 4.0 MPa+ fixed bed pressurized gasification technology, the fixed bed slag gasification technology, the pressurized fluidized bed gasification technology and other critical technologies. It also proposed to push forward large-scale, high-efficiency synthesis and refining technologies, as well as the research and development of key technologies such as high-temperature Fischer-Tropsch synthesis, low-temperature Fischer-Tropsch synthesis, direct coal gasification, methanation, large-scale methanol synthesis, large-scale ammonia synthesis, and methanol to ethylene and propylene, synthetic gas to ethylene glycol conversion technologies. Breakthroughs were also expected in high-performance gas purification and separation technologies, as well as the over one million t/a alcohol (ammonia) scale low temperature methanol washing technology.

Today, China leads the world in the number of 600°C USC units, with power generation efficiency above 45%. The 1,000 MW direct air cooling unit with independent intellectual property rights has been put into operation, the 300 MW subcritical parameter CFB is in large-scale commercial operation, and the 600 MW USC CFB is under development and construction. Major achievements have been made in 100 kW and MW gas turbine technologies for the distributed combined heating, cooling and power system. A demonstrative project is being built for the 250 MW IGCC unit with proprietary gasification technology, and a demonstrative 120,000 t/a coal gas capture unit has been put into operation.

The Chinese Academy of Sciences has played a leading role in the development of coal utilization and transformation technologies in China. The CAS Institute of Process Engineering has carried out research on coal pyrolysis for co-generation of coal tar, pyrolysis gas and power, set up a 10 t/h industrial pilot test platform in Hebei Province, and demonstrated the 10,000 t lignite quality improvement technology in Xinjiang. The Shanxi Institute of Coal Chemistry under CAS has cultivated technological demonstration capabilities in fluidized bed ash agglomerated application, FT synthesis and mixed alcohol synthesis. The CAS Institute of Engineering Thermophysics is a leading provider of CFB technology and a major developer of gas turbine and IGCC technologies. Also, the Dalian Institute of Chemical Physics has scored a number of world-leading achievements in catalyst development and catalytic process research. Besides, many CAS institutes have accumulated rich expertise in the capture, storage and utilization of carbon dioxide.

## 4. Future development goals

According to *China's Energy Development Roadmap to 2050*, it is anticipated that in 2020, most of China's clean coal utilization technologies will be put into commercial application. The high-performance power generation technologies based on advanced combustion technologies will become mature, and $CO_2$ capture and storage technologies will be well developed to enter the commercial application phase.

By the year 2035, all of China's clean and high value added coal utilization technologies will find wide commercial application. The technologies for large scale green transformation of gasification agents will contribute to coal resource application by over 50%, and new coal combustion and power generation technologies will contribute to the application of coal-based power generation by over 80%. The growth of coal use in China is expected to constantly drop toward zero or even a negative percentage.

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# Independent Research and Development of Key Technologies and Equipment for Deep Earth Exploration

## 1. Scientific connotation and significance

As a system engineering technology for the exploration and rheology studies of continental lithosphere, deep Earth exploration uses the most advanced science and technologies to obtain the basic information about the Earth's interior and serve the sustainable supply of energy and resources as well as the early warning of natural disasters. Today, deep Earth exploration has become one of the forefronts of earth sciences[1].

Deep Earth exploration requires a core and integrated technique system for the development of key detecting technologies and facilities which can penetrate different depths to precisely extract the internal structure and physical properties of the Earth, together with a technology platform for the processing, imaging and explanation of data[2]. By detecting the planet's deep interior in typical regions and by cutting open the crust and upper mantle, the internal structure of the Earth can be revealed and the key problems in earth sciences, resources and environment effects will be solved.

There is a large gap between China and the world advanced level in deep Earth exploration capabilities. China's deep reflection seismic profile is only 1/13 of that of the United States or 1/5 of Britain's or Russia's. The exploitation depths of current deposits in China are largely less than 500 m, though a few have reached 2500 m to 4, 000 m depth. The prediction of mineral resources below and around known deposits will be a new direction for China's deep Earth exploration in the future[3], and new theories and techniques are badly needed for seeking after deeper mineral resources.

*Key technologies and core equipment for deep Earth exploration can induce innovations in energy/resources accumulation and metallogenic theories, and provide steady technical support for the search and exploitation of deep resources*. It is an important strategy to promote sustainable economic development by detecting the Earth's interior structure, composition, and by revealing the relationship between the geodynamic evolution of the Earth system and its resources and environment. They help reveal the subsurface detailed structure, composition and controlling factors during the formation of mineral deposits, and break technical bottlenecks to create new "spaces" for prospecting. Besides, by deepening our understanding of the formation, sedimentation, source rocks, temperature and pressure field of the deep Earth, it is helpful to make oil and gas exploration more comprehensive and objective[4], which would in turn provide valuable resources for more comprehensive research like in geological survey, groundwater resource evaluation and mineral resources and energy detection, and offer scientific evidence and technical support for deep and important mineral resources.

*Key technologies and core equipment for deep Earth exploration can help reveal the mechanisms and processes of geological hazards and provide scientific evidence for the high precision warning and forecast of those disasters.* By showing the deep layer structure and dynamic processes of the Earth, it can provide direct and convincing data to reduce and assess disasters. The data helps to unravel the mechanisms and processes of geological hazards, the latent regions and deep background reasons of major disasters, offers a theoretical basis for high precision warning and forecast of those disasters, and can help reduce the damages of the hazards.

*Key technologies and core equipment for deep Earth exploration supports the study of deep Earth layers with basic data.* High precision geophysical and geochemistry prospecting technologies can be used for detailed detection and theoretic simulation of the layers of the deep Earth to reveal its internal structure, composition and physicochemical properties, to clarify complicated physical and chemical actions between lithosphere and the deep mantle, to show physical and chemical processes of the formation and transformation of lithosphere, and to recover complete images of the evolution processes[2]. Nowadays, the development and progress of earth sciences are increasingly dependent on data and our understandings of the deep Earth. That is to say, there can hardly be any true progress in earth science theories without deep Earth detection[5].

## 2. Global research progress

In the 1970s and 80s, the United States implemented the COCORP Project (the Consortium for Continental Reflection Profiling) which opened a new gateway to deep reflection seismic exploration of the deep Earth and enabled the detecting depth and precision to achieve the levels which had never been reached before. Since then, many deep Earth exploration projects has been launched one by one, such as DEKORP, LITHOPROBE, Glass-Earth and EarthScope, with technologies based on the principle of seismic wave as a key means for exploration and deployment. At present, the deep seismic reflection profile is widely used all over the world, combined with wide-angle reflection and refraction seismic profile and broadband digital seismic mobile stations technologies. However, other non-seismic exploration technologies, such as the magnetotelluric sounding method, the large area and high accuracy gravity and magnetic survey and the terrestrial heat flow are usually important auxiliary means[1,6]. With strengths in drilling technology and the research and development of electrical and mechanical equipment, Russia and Germany still lead the world in the science-based drilling of superdeep holes, including Russia's Kola superdeep borehole (12,261 m deep) and Germany's KTB (9,101 m deep).

### 3. China's advantages

China's deep Earth detection technologies are gradually going mature. It has established high accuracy observational methods based on array and electromagnetic parameters of the standard network, as well as refined, standard data processing and inverse techniques at world advanced level. The performance of key technologies for seismic exploration and electromagnetic detection has caught up with developed countries. China has developed a continental scientific drilling with drill depth of 10,000 m, which is the deepest in Asia, and its digital control technologies have reached world level. The three dimensional structures of the Earth and the dynamic simulation abilities have been improved, and a numerical simulation platform for deep detection has been established, which is one of the world's few platforms for lithosphere dynamics research[5].

Between 2008 and 2012, China conducted a deep exploration program called SinoProbe. China's limited research and development abilities cannot meet its demand for scientific drilling and solid mineral resources exploration[7]. Independent research and development of deep detection instruments should be improved to reduce China's reliance on import and break foreign monopoly, and to develop our own technologies such as the distributed self-localization broadband seismic exploration system, so that breakthroughs can be achieved in key research equipment for deep Earth exploration and the scientific and technological advancement in resources detection in China can be promoted.

### 4. Breakthroughs to be expected in the future

China needs to develop the key equipment for deep Earth detection, solve technical difficulties, integrate related technologies, and carry out the continuous monitoring and data accumulation of the deep layers of solid Earth at multiple temporal-spatial scales to gradually build up its stereoscopic and dynamic monitoring and analysis abilities. It will also develop the high energy geophysical detection instruments with high depth detection abilities, the large area and high efficiency unmanned aerial vehicle detection system, the aviation superconducting full tensor magnetic gradient measurement system, the multi-channel transient electromagnetic exploration system, the seismic exploration system, the highly integrated and ultra-deep exploration facilities, the comprehensive mobile platform for massive and multi-type data, and software for geophysical data processing and interpretation and so on[6, 8].

As for "exploring deep deposits", China will hopefully achieve breakthroughs in three aspects: the magnetic sensors, the sub-bottom profiling system and the magnetic satellite payloads. The effective integration of software development, metallogenic research and exploration practices can induce the core theories and detection technologies China needs for its "transparent 4000 m underground program"[3].


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# Large-scale Renewable Energy Power Generation and Distributed Grid Will be Commercially Available

### 1. Scientific connotation and significance

Restrained by the growing depletion of fossil fuels and the need for environment protection, our modern society is bound to face a new energy transition, a transformation from heavy dependence on fossil fuels to the use of renewable and new energy. The main form of renewable energy utilization is power generation, when power can be generated by centralized plants (large wind farms, photovoltaic power stations, solar thermal power stations, etc.) or distributed systems (such as rooftop PV systems, dispersed wind power generation, and biomass power generation). With future technological breakthroughs like PV parity, offshore wind power generation, deep geothermal power generation and rapid reduction in cost, the large-scale development of renewable energy will be accelerated in the future.

To realize the large-scale development of renewable energy, the power grid should be capable of accommodating renewable energy power of such scale. The key is to establish a new power system network structure and develop an integrated smart grid combining AC (alternating current) with DC (direct current) systems and centralized with distributed power generation. Breakthroughs in DC grids, distributed power grids and advanced energy storage technologies will provide strong supports for large-scale grid connection of renewable energy power. These breakthroughs include: (1) The modeling of a power system which can accommodate large-scale renewable energy power, and by unraveling its characteristics and working rules to lay the foundation for the planning, design, operational control, energy management and failure protection of the system. (2) The development of new power facilities such as devices for power conversion, control and protection in future DC grids. (3) The realization of high-efficiency energy management of power grid based on demand side response management technologies, distributed power grid technologies, and advanced information communication and intelligent control technologies.

## 2. Recent progresses in the world

In recent years, the renewable energy industry has made great achievements with strong policy support in many countries and regions. According to the *Global Trends in Renewable Energy Investment 2012*[1] released by UNEP and the *Renewables 2012 Global Status Report*[2] released by REN21, more than 138 countries in the world have set their goals for renewable energy development. More than half of the global new power installation in 2012 came from renewable energy, which accounted for 26% of the global total installed power capacity and contributed to 21.7% of the world's electric power. As estimated by the International Energy Agency, by 2016, the total amount of electricity generated by renewable energy such as hydro-power, wind power and solar power will exceed electricity generated from natural gas and amount to twice as much as nuclear power[3]. By 2050, renewable energy will produce 57% of the world's electricity and become the dominate energy source on Earth[4].

Wind power has been applied in over 60 countries, and solar PV has rapidly extended to emerging countries and regions. The world's total investment in the renewable energy sector in 2012 stood at 244 billion US dollars, which was five times more than that in 2004. Renewable energy has played an important role in some countries and regions, and they constitute a growing proportion of energy and electricity supply in many places. In 2011, renewable energy accounted for 13.4% of energy end-use and 20.6% of electricity generation in the EU. In 2012, power generated from renewable energy made up 70% of new power installation in EU and in the US the proportion was 50%. In 2012, renewable energy met 22.9% of electricity demand in Germany; in Denmark, renewable energy contributed to 24% of the nation's entire energy consumption and more than 40% of its electricity came from renewable energy. About 32% of electricity supply in Spain came from renewable energy.

With the technological breakthroughs, large-scale application and cost reduction in the renewable energy sector, renewable energy will play an increasingly important role in the energy sector in future. To cope with challenges from energy and environment and climate change, the international community attaches more and more importance to the development of renewable energy, and the governments have rolled out policies and strategies on low-carbon energy transition. For instance, the Obama administration proposed that by 2035 clean energy (including renewable energy) is to meet 80% of the electricity demand in the United States[5], and has approved the Sunshot Initiative, the offshore wind power joint development strategy and the power grid modernization program to impel the scale-up of its renewable energy sector and power grid infrastructure. The EU set a goal that by 2020 renewable energy will contribute to 20% of the total energy consumption in EU countries[6] and that by 2030 the proportion will rise to 30%. Via the construction of smart grids, EU aims to promote the development of renewable energy and distributed power generation and to lead the transition of the entire industrial model[7]. In Japan, after the Fukushima Daiichi nuclear disaster, the government proposed a green energy revolution strategy aiming to make renewable energy the basic energy form for the Japanese society in future. By 2030, the electricity generated by renewable energy in Japan will triple that in 2010, and the use of green energy will be expanded via technological development and power system reform to propel inexpensive and stable power supply[8]. In July

2012, Japan began to adopt the fixed price purchase policy in its renewable energy sector to promote large-scale domestic application[9]. Germany implemented an energy transition strategy that promises to abandon nuclear power after 2022[10] and guarantee electricity supply by other energy forms like offshore wind power and distributed solar power systems. It proposed that by 2020 renewable energy power generation will make up 35% of the nation's total electric consumption, by 2030 50% and by 2050 over 80%. It will also invest heavily on power grid expansion, smart grid construction and energy storage research to safeguard energy transition in the nation. Denmark presented a grand strategy that it is going to get rid of the reliance on fossil fuels and use 100% renewable energy by 2050[11].

## 3. Goals and progresses of renewable energy development in China

To adapt to economic pattern transformation and energy structure adjustment, China takes the development and utilization of renewable energy as an important part of its energy development strategies. China proposed that by 2015 and 2020 respectively, non-fossil fuels will account for 11.4% and 15% of national primary energy consumption. *The 12$^{th}$ Five-Year Plan for Energy Development* pointed out that China should combine the development and utilization of intensive and dispersed renewable energy, with priorities on wind power, solar power and biomass energy. By 2015, the installed capacities of electricity generated from wind energy, solar energy, biomass energy and municipal solid wastes are expected to reach 100 million KW, 21 million KW, 13 million KW and 3 million KW, respectively. Meanwhile, China will speed up the development and utilization of distributed renewable energy such as wind energy, solar energy, small-scale hydropower, biomass energy, marine energy and geothermal energy. By 2015, distributed solar power generation will reach 10 million KW, and a total of 100 new-energy exemplary cities which primarily rely on the use of distributed renewable energies will be set up[12]. China issued *the 12$^{th}$ Five-Year Plan for Renewable Energy Development* to make strategic arrangement on the development of renewable and new energy in the next five to ten years, as well as the *12$^{th}$ Five-Year Plan for Solar Power Industry*, *the Special Plan for Wind Power Technology Development*, and *the Special Plan for Solar Power Technology Development* to guide key industries such as PV and wind power industries.

Currently, China has made great progress in the research and application of large-scale wind and solar power generation, distributed renewable energy and distributed power grid. China has become a leader in the renewable energy sector, with the world's highest renewable energy total installed capacity and hydro-power and wind power installed capacity. The installation of solar water heaters in China is way ahead of other countries when PV installed capacity is on dramatic rise. In 2012, renewable energy made up 10.3% of China's primary energy consumption, with a proportion of 28.1% in electricity installation and over 20% in energy production, when solar power production exceeded nuclear power production for the first time[13]. China's renewable energy industry has entered an important phase featuring comprehensive, rapid and large-scale development. Organizations including the State Grid Corporation of China, China Southern Power Grid, the Chinese Academy of Sciences and some domestic colleges and universities have achieved great advances in smart micro-grid and distributed grid research, by building up a number of multi-functional smart micro-grids and distributed grid demonstration systems which successfully implemented in situ utilization of renewable energy, intelligent use of electricity, intelligent buildings and smart homes, and which improved grid reliability, power supply quality and power distribution efficiency as a whole. Based on this, further breakthroughs in DC grid, distributed grid and advanced power storage will give strong technological support for China to meet its goals for large-scale renewable energy development set out in *the 12$^{th}$ Five-Year Plan of Energy Development* and to realize the safe and efficient utilization of renewable energy on a large scale.

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# Efficient and Clean Utilization of Waste-generated Energy Gives Birth to an Emerging "Urban-mining" Industry

## 1. Scientific connotation and significance

The large amount of wastes on the earth makes a gigantic energy and resource bank, which can be used both directly for generating new energy and for saving resources through recycling and regeneration. Generally speaking, the efficient and clean utilization of waste-generated energy refers to the recycling of a great amount of valuable substances from the solid materials that have quitted the production link or consumption field via certain technical, economical means and management measures, to achieve biosafety disposal, pollutant emission reduction and the comprehensive utilization of wastes for both economic and public welfare[1]. At present, the efficient and clean utilization of waste-generated energy is mainly implemented through the use of renewable energy, industrial solid waste resources and waste and sludge resources. Each year, China produces more than 10 billion tons of urban solid wastes including domestic waste, municipal sludge, livestock and animal manure, industrial residues, agricultural and forestry residues, construction waste and electronic waste. If these wastes can be used effectively, a great amount of energy products such as heat, biogas, organic fertilizers and eco-building materials can be developed. In particular, organic waste has great potential for resources utilization, and a great amount of waste paper, plastic, rare metal and steel and iron can be recycled from such wastes.

Based on such reality and years of scientific research, mass breakthroughs in relevant technologies for the efficient and clean utilization of waste-generated energy will hopefully be achieved in the future, and the circular economy model based on substance flow, energy flow and economy flow as well as the waste inverse production technology system will be formed to lay a theoretical and technical foundation for the emergence of the "urban mining" industry[2].

## 2. Recent progresses in the world

(1) Technologies for renewable resources utilization

Technologies for renewable resources utilization mainly include those for the recycling of scrap metal, dismantling and re-use of waste and worn electrical and electronic appliances, remanufacturing of waste mechanical and electrical products and high-value utilization of waste polymer materials[1]. These technologies have found wide application in developed countries. For instance, the COS-MELT tilting furnace technology developed by Italy supports the direct refining and production of high quality, low oxygen bright copper rod from scrap copper, which remarkably improved the standard and quality of copper utilization. In Europe, Japan and the US, the technology for the intelligent sorting and clean extracting of waste electrical and electronic appliances have seen mass application in many renewable resource enterprises. Europe and America are positively pushing forward the re-use of obsolete or worn-out components and parts on new products. Such technologies as high-temperature jet cleaning, overlay welding, thermal coating, and laser have been applied widely to the remanufacturing of used mechanical and electrical product for automobile and engineering machinery. The study of waste resources technology now focuses on the technology to fulfill full lifecycle utilization of waste or used high polymer materials.

(2) Technologies for turning industrial solid wastes into resources

The technologies for turning industrial solid wastes into resources include those for the utilization of pulverized fuel ash and gangue, the comprehensive disposal of metal residues, the comprehensive utilization of industrial by-product gypsum, and the use of industrial biomass waste resources[1]. As major mineral resources in foreign countries are of relatively higher grade, the clean mining and metallurgy technique sees wide application in these countries, and the residues contain lower content of harmful ingredients. The utilization of such waste is mainly targeted at high-value utilization of valuable ingredients. Since the yield of industrial by-product gypsum in developed countries is relatively low, and the price of natural gypsum is relatively high, the utilization is to produce building materials with it as a replacement of natural gypsum. By far, a comprehensive technology system has been generally developed in this regard.

(3) Technologies for the utilization of waste- and sludge-based resources

Technologies for using waste and sludge as resources include those for the utilization of urban domestic waste, construction waste and the disposal and utilization of sludge [1]. Developed countries have seen rapid advancement in waste and sludge resource disposal. For example, Germany has built 55 projects for urban domestic waste disposal and biogas utilization, which not only are self-sufficient in energy supply, but have started to provide gas to transportation and residential quarters. As for construction waste, its utilization rate is 50% in EU and 97% in South Korea and Japan. The technologies and supporting equipment for biomass gas production from anaerobic sludge digestion have been well developed and widely applied in Europe and North American countries.

## 3. China's advantages

Compared with developed countries, China still stays at the low end of the global resources circulation industry chain in terms of efficient and clean utilization of waste-generated energy. The low added-value of recycled products and the inadequate utilization scale and level both call for an improvement in the utilization rate and resources yield via technological innovation, so as to safeguard national resources supply[3]. At present, China has stepped up the scientific research in related fields and launched several key R&D programs, such as the study on the mechanism of efficient and clean utilization of combustible solid wastes.

The Chinese Academy of Sciences (CAS) has its own advantages on the subject. The CAS institutions involved in the research include the Institute of Process Engineering, the Guangzhou Institute of Energy Conservation, the Research Center for Eco-Environment Sciences and the Qingdao Institute of Bioenergy and Bioprocess Technology. For instance, scientists from the Institute of Process Engineering have built the world's first set of production line for full-component, high-value chrome/vanadium slag utilization with capacity of 15,000 t/y, using independently developed technologies for the efficient and clean transformation, separation and pollution control of chrome/vanadium. They achieved the production of high-purity vanadium pentoxide directly from vanadium-containing waste with 90% recycling rate [4]. The Guangzhou Institute of Energy Conservation has been engaged in the study of harmless treatment and disposal of waste resources for more than 20 years, reaping abundant results in fields like the physical and chemical properties of solid waste components, the research and demonstration of harmless disposal and treatment, etc. The State Key Laboratory of Environmental Chemistry and Ecotoxicology under the Research Center for Eco-Environment Sciences, CAS is an important base for persistent organic pollutants research in China, and its dioxins detection and analysis capabilities have reached international level. The Thermal Chemistry Transformation Team from the Qingdao Institute of Bioenergy and Bioprocess Technology has been working on the disposal and treatment of renewable substances (such as biomass, solid waste and coal), the thermal chemical energy utilization and development of catalytic materials in recent years.

## 4. Goals to achieve in the future

According to a special program on waste resource utilization under the *12th Five-Year Plan* framework, by 2015, the production of regenerated metals in China will exceed 12 million tons, which means a 10% to 15% decrease in the country's reliance on import. In recent years, China saw a steady growth in the output value of its waste resource utilization endeavor at 10%–20% per year. In 2010, the output value exceeded one trillion yuan, accounting for over 60% of the total output of the energy and environment industry. It is estimated that by 2015, the output will stand at two trillion yuan, based on likely technological breakthroughs in the following fields: waste energy/resource transformation and utilization, hydrogen and methane production through anaerobic fermentation of cogeneration of urban and agricultural solid waste, urban sludge-based microbial power generation and related equipment, mixed combustible solid waste oxygen-rich pyrolysis and gasification and gas purification and conditioning, advanced pyrolysis combustion boilers for urban domestic combustible solid waste, biodiesel production from hogwash oil and biobutanol production from industrial waste.

In the next 30 years, 80% of the world's underground mineral resources will be transferred to be above ground, and the supply of materials made from waste-generated energy or resources will increase from the present 30% to 80% of the global total[5].

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# Regional High-voltage DC Grid Will Be Established in China

## 1. High-voltage DC transmission technology is the key to interconnecting large-scale power generation from renewable energy

China has plentiful renewable energy sources, which will serve as the dominant energy sources in the future. Statistics show that each year, all land in China receives a total solar radiation equivalent to the energy of 2,400 billion tons of standard coal. China's total reserve of wind energy at ten meters above the earth amounts to about 3.226 billion kW, of which one billion kW is available for development and utilization. The theoretical reserve of China's hydraulic power is nearly 700 million kW, accounting for 40% of the total conventional energy sources of the nation.

By the end of 2011, the installed capacity of the grid-connected renewable-energy-based power generation in China had reached 51.59 million kW, accounting for 4.89% of the nation's total installed capacity. Among that, the grid-connected wind power was 45.0511 million kW and the grid-connected solar photovoltaic power was 2.1430 million kW. In 2011, the grid-connected renewable-energy-based power generated in China was 93.355 billion kWh, about 2% of the country's total power generation, among which the grid-connected wind power generated was 73.174 billion kWh and the grid-connected solar energy generated was 914 million kWh[1].

However, restricted by the consumption and accommodation capacity of China's electric system, most of the renewable energy has not been effectively utilized. There are even phenomenons like "wind abandonment" and "light abandonment". On the other hand, renewable-energy-based power generation, including wind and solar power generation, has such characteristics such as intermittence, fluctuation and dispersion. Its power generation mode is totally different from that of the power generation based on conventional energy. With China stepping up and expanding the construction of its renewable energy bases, it is more and more difficult for the existing AC grids across the country to cope with the development. The conventional electric equipment, grid structure and operation technologies are becoming increasingly inadequate for receiving ultra-large-scale renewable energy, bringing revolutionary challenges to the dynamic safety and stability of China's power grids. To cope with such situation, new technologies, equipment and grid structures are needed to meet the profound changes in future energy layout.

The multi-terminal DC transmission system and DC grid technology based on conventional and flexible DC are one of the effective technical means to solve this problem. In recent years, greater and greater efforts have been put into the study of DC transmission and distribution grid technology. Developed countries and regions such as the US and Europe have started DC grid construction and the research and development of relevant technologies. Transforming from the AC mode to the AC-DC mode or pure DC mode will make the grid safer and more stable, with significant impacts on the production, transmission, distribution and utilization of electricity and the structure of the electric industry. Such transformation will also give birth to a group of new and high-tech industries.

## 2. Status and technical demands of high-voltage DC grid in China

China started developing high-voltage DC grid technology quite early. In August 1990, China's first large-scale DC transmission project, the ± 500 kV DC transmission from Gezhouba to Nanqiao, was completed. It has a transmission distance of 1,054 kilometers and a rated transmission capacity of 1.20 million kW. After this, China built ± 500 kV DC transmission projects from the Three Gorges to Changzhou, Shanghai and Guangdong, respectively, with a total DC line length of over 2,900 kilometers.

In recent years, guided by the ideology of building strong AD-DC inter-grid, China began to promote the construction of ultrahigh-voltage DC transmission projects. On July 8, 2010, the ultrahigh-voltage DC transmission demonstration project from Xiangjiaba to Shanghai was successfully put into operation. At present, China is building a number of other ultrahigh-voltage DC transmission projects, including the Jinping–Sunan Project, the Hami–Zhengzhou Project and the Xiluodu–Jinhua Project. According to the National Grid Program, China also plans to build a North China–East China–Central China 1,000 kV AC main grid, which will connect with the northwest and northeast sending-end networks via DC asynchronization. The power needed from the outside will be transmitted in via ultrahigh-voltage DC and ultrahigh-voltage AC channels separately. That is, the large-scale coal power and wind power from Shanxi, western Inner Mongolia, northern Shaanxi, Ningxia and Ximeng, the hydropower from Sichuan, and the nuclear power from coastal provinces will be transmitted in via ultrahigh-voltage AC channels; the large-scale coal power and wind power from northwestern and northeastern China and the large-scale hydropower from southwestern China will be transmitted in via ultrahigh-voltage DC transmission channels[2].

China's existing grid operates in the AC mode, and there has been a huge industry chain of electrical engineering and electric equipment manufacturing compatible with that mode. Concerning the study of DC grid, scientists from the Institute of Electrical Engineering, Chinese Academy of Sciences have been working on subjects like the rationality of China's future DC grid construction and grid structure, the complementary utilization mode of wide-area renewable energy resources, the superconducting DC transmission technologies and so on. The institute launched the construction of a DC grid demonstration system based on several complementary energy resources (including energy storage systems), and has completed the building of a 360-meter, 10,000-ampere superconducting DC transmission demonstration project.

In the future, China has to solve a number of key technical problems in order to make systematic and overall breakthroughs in DC grid theories and key technologies. On the information level, the problems include the research and development of new, high-performance sensors and their network, the power prediction and forecast technologies, the rapid transmission of wide-area mass data, the modeling and simulation technologies for DC grid, the DC grid cloud computing and sea computing technologies, the structuring of the universal information platform of wide-area DC grid, and information safety technologies. On the physical level, problems include grid evolution, the structure of future DC grid, theories on the safety and stability of DC grid, new electric and electronic devices, high-voltage large-power electric and electronic equipment, DC breakers and current-limiting technologies, the coordinated dispatch and optimized operation control of wide-area DC grid, fault location and grid restructuring, distributed grid and its access, energy storage technologies, power superconducting technologies, and advanced electrical materials.

## 3. Future development goals and technologies

It is an urgent task for China to develop DC grid for solving its future problem of providing renewable energy with a large-scale access to the grid. It is expected that China will make breakthroughs in DC grid theories and multi-terminal DC transmission technologies and build regional DC grid in northwestern China, a region with abundant renewable energy resources. In this way, China will hopefully realize the regional, large-scale application of renewable energy resources and increase the proportion of renewable energy in the energy sector.

According to the *National 12th Five-Year Plan for Energy Technology (2011-2015)*, during the *12th Five-year Plan* period, China aims to produce FACTS devices and develop short-circuit fault current limiters, DC circuit breakers, electric and electronic transformers, the superconducting energy storage system and the superconducting DC transmission demonstration system. VSC-HVDC transverters will find application in the 160 kV system.

China's DC grid development goal is that by 2020, a theoretical, technological and standardized system for DC grid that fits the reality of China will be established respectively, and breakthroughs in DC grid key technologies will be achieved so as to lay a solid foundation for the development of new generation of power grid in China.

The future revolutionary transformation of the grid from AC to DC operation mode will nurture huge opportunities for scientific and technological innovation and many strategic emerging industries, and systematic breakthroughs in DC grid technologies is to offer technical support for China's construction of an integrated clean energy system in the future.

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# Major Breakthroughs Will Be Made in China's Manned Space Program, Lunar Exploration and Other Space Missions

In the recent 20 years, China has carried out several major space programs and made great achievements, which aroused close attention by the international space community. From 2007 to 2013, the manned rendezvous and docking missions were successfully completed, the Chang'e-1, Chang'e-2 and Chang'e-3 lunar probes were successfully launched, and various manmade satellites represented by the Beidou Navigation Satellite System and the High Resolution Earth Observation System were progressively implemented in orbit. China is stably building itself into a space power.

## 1. China's Manned Space Program

In 1992, the Chinese Manned Space Program was approved by the government, and became the largest and most complicated space activity in the nation's history[1].

The Program follows a three-step development strategy. The first step is to launch a manned spacecraft, establish an experimental platform for the spacecraft with preliminary supporting facilities, and carry out application experiments in space. The second step is to launch a space laboratory and conduct space application of a certain scale with man-tending on a short-term basis, by acquiring technologies related to astronaut extravehicular activities, rendezvous and docking. In fact, the first phase of this step had been completed with the success of the Shenzhou X mission, and the second phase — launching a spacelab — is under way. The third step is to set up a space station and provide a solution to space application of larger scale with man-tending on a long-term basis[2].

The Chinese Space Station (CSS) will be established around 2020 and is expected to operate for 10 years. The payloads on CSS will consist of a number of space science experimental platforms, several major research facilities with international competitiveness, and independent payloads used for specific research purposes. The application of the space station will cover the following fields: aerospace medicine; space life sciences and biotechnologies; microgravity fluid physics and combustion science; space materials science; microgravity-based fundamental physics; space astronomy and astrophysics; space environment and space physics. Such a space laboratory will become another important platform after the International Space Station for manned space science research and application.

With CSS, China will hopefully achieve a number of major breakthroughs at the frontier of space science and became a world power in the field. With the implementation of China's Manned Space Program, more and more countries and organizations have expressed their intention to participate in cooperation with China, and CSS may become the next role model for international cooperation in space exploration[3].

## 2. China's Lunar Exploration Program

Lunar exploration is an inevitable step for human beings before they can go into deeper space to explore the universe. The Chinese Lunar Exploration Program, the first of its kind in China's history, was launched in 2003 with a three-step implementation plan, namely "orbiting", "landing" and "returning". The first step is to launch a spacecraft to orbit around the moon. The second step is to launch a probe which will land on the moon's surface for geological exploration. In the third step, based on the success of the landing mission, lunar samples will be collected and carried back to the Earth. These activities will lay a solid foundation for manned lunar landing. The whole program is estimated to take 20 years[4,5].

The success of Chang'e-1 and Chang'e-2 achieved the strategic goals of the first stage of the program. The Chang'e-3 probe was launched on December 2, 2013 to carry out the second stage of the program. The probe successfully landed on the moon on December 14, and started to perform automatic patrol exploration on lunar surface. The scientific objectives of the second stage include lunar surface topography and geology survey, material composition and resources survey, as well as investigations into the lunar internal structure, sun-earth-moon space environment and lunar-based astronomical observation. The second stage will lead to a large amount of technical innovations, which can be applied not only in other space programs but in civilian fields such as astronomical observation, artificial intelligence and microelectronics.

The major scientific objectives of the third stage include in-situ investigation and analysis, the analysis of return samples, and study on the origin and evolution of the moon and the Earth-Moon system. With the completion of these three steps, China will become the third country in the world, after the United States and Russia, to be able to take soil samples from the moon back to the earth.

### 3. The Beidou Navigation Satellite System

The Beidou Navigation Satellite System is a global navigation satellite system independently developed by China. Its research and development follows a three-step strategy. Step I: A pilot system of Beidou was started (first generation) in 1994 and began to provide regional active service in 2000. Step II: The construction of Beidou (second generation system) was kicked off in 2004, which obtained regional passive service capability in 2012. Step III: By 2020, the Beidou will realize global passive service.

In the next decade, the Beidou System will be completely established for independent navigation, positioning and timing services on the global scale, and safeguard China's national security. It will become one of the four global navigation and positioning systems, on a par with the Global Positioning System of the United States, the European Galileo System and the Russian GLONASS System. Currently, the second generation chip of Beidou has been released and passive positioning, navigation and timing services have been provided to the Asia-Pacific region. The tremendous commercial value of the system will be gradually realized. With the completion of the system in 2020, it is going to play an important role in many fields such as mapping, transportation, emergency rescue and national security[6,7].

### 4. High-Resolution Earth Observation System

An earth observation system is a system to observe the Earth from space, and is an outstanding landmark of the progress of geoscience in the 20th century. Currently, many countries are making efforts to develop their earth observation technologies, in which the United States, France, Germany and Russia are leading the world. Countries and regions such as Japan, India and Europe have already launched their earth observation satellites[8].

China's High-Resolution Earth Observation System is one of the 16 major S&T projects listed in the *Outline of National Programs for Medium- and Long-Term Scientific and Technological Development (2006-2020)*. It aims at the design and establishment of a high resolution earth observation system based on satellites, airships of the stratosphere and aircrafts, and enabling China for all weather and all time observation from space by the year 2020. It will be made up of a space-based observation system, a near space observation system, an aviation observation system, a ground base and several application systems. The project was officially approved in May 2010, and construction was officially started in 2012. According to plan, it is to launch five to six observation satellites during the *12th Five-Year Plan* period, among which the first satellite, GF-1, was successfully launched on April 26, 2013 and entered service[9].

The project will promote China's independent acquisition of high-resolution observation data, facilitate the establishment of the spatial information application system, boost the development of its satellite and application technologies, and answer the needs brought forward by modern agriculture, disaster prevention and mitigation, resources survey, environment protection and national security. It will also provide strong support to application demands in fields such as land survey and utilization, geographic mapping, ocean and climate meteorological observation, water and forestry resources monitoring, fine management of urban area and traffic, health and epidemic surveillance and earth system research, etc., and support local demonstration application and accelerate the development of China's space information industry[10].

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# China's Space-science Satellite Series is Taking Shape and Will Hopefully Achieve Important Discoveries at Scientific Frontiers

China has made great progresses in space technologies since the launch of its first artificial satellite and prepared itself for the rapid development of space science. By using foreign observation data for many years, a large number of space scientists have been cultivated in China[1]. However, except for a few space science experiments conducted on several satellites and the Double Star mission, China is obviously short of its own science satellite plans and first hand data. China has yet to give full play to the driving and leading role of space science satellite programs in the development of space technologies.

To ensure the sustainable development of space science, narrow the gap between China and developed countries in cutting edge scientific discoveries and application-oriented innovation, and inject new vitality into the development of space technologies in China, CAS has launched a strategic priority research program on space science in January 2011 and deployed a series of scientific satellite missions.

## 1. Hard X-ray Modulation Telescope (HXMT)

(1) Scientific objectives

HXMT will study the properties of black holes and the physical law under extreme conditions, perform broadband X-ray (1–250 keV) sky surveys, probe supermassive black holes and unknown high-energy celestial bodies covered by dusts, and study the properties of cosmic background radiation in hard X-ray band. The telescope can also perform high sensitivity broadband fixed point observations on major celestial bodies to detect their time variations and energy spectrum characteristics, so as to facilitate the investigation on the dynamics and high energy radiation processes in compact objects and strong gravitational fields of black holes.

(2) International development status

At present, telescopes capable of hard X-ray band observation in service include the International Gamma-Ray Astrophysics Laboratory (INTEGRAL) launched by ESA in 2002 and the Swift and Nuclear Spectroscopic Telescope Array (NuSTAR) launched by NASA in 2004 and 2012, respectively. In addition, Japan and India are planning to respectively launch the Astro-H X-ray telescope and the ASTROSAT satellite between 2013 and 2014.

(3) China's foundation and progress

China's HXMT is based on the innovative hard X-ray imaging technology and the mature detector technology developed by domestic scientists. Once launched, it will make important original achievements. So far, the development of a ground-based prototype of the telescope's payload system has finished, and a successful balloon test has been completed. Besides, the Ziyuan-2 satellite platform as a mature and reliable facility will meet HXMT's requirements in general performances[2]. As China's first astronomy satellite, HXMT was officially approved in March 2011 and is in Phase C now.

## 2. Quantum Experiments at Space Scale (QUESS)

(1) Scientific objectives

The two main objectives of QUESS are: (a) to conduct high speed satellite-ground quantum key distribution experiments and large-scale quantum key network experiments, so as to facilitate breakthroughs in the practical application of space-based quantum communication technology; (b) to perform quantum entanglement distribution and quantum teleportation experiments at spatial scales, so as to boost experimental investigation on the completeness of quantum mechanics. To meet these goals, QUESS comprises four in orbit experiments: the high speed satellite-ground quantum key distribution experiment, the large-scale quantum key network experiment, the satellite-ground quantum entanglement distribution experiment and the ground-satellite quantum teleportation experiment.

(2) International development status

Europe plays a leading role in this regard. From supporting a series of quantum communication research since 2002, ESA made a new world record by promoting the transmission distance of single-photon entanglement to 144 km in 2007[3], and proposed the Space-QUEST project which uses the International Space Station (ISS) as a quantum communication repeater station[4]. In 2008, a research team from Europe recognized for the first time a single batch of photons bouncing back from a satellite 1,500 km away from the earth's surface, which marked a major breakthrough in space encryption transmission of quantum information[5]. In 2012, the world's first successful primary quantum network was constructed by German scientists and its remote entanglement worked for 100 μs[6].

(3) China's foundation and progress

With outstanding achievements already made by its scientists, China is expected to realize large scale quantum communications for the first time in the world. Since 2005, scientists from CAS have obtained many breakthroughs, including the world's first free space two-way entanglement distribution over a distance longer than the equivalent vertical thickness of the atmosphere[7], the 16 km free space quantum teleportation, and the free space quantum teleportation and two-way entanglement distribution at 100 km level. In early 2013, CAS completed the world's first comprehensive ground-based verification test of satellite-ground quantum key distribution, laying a sound technical basis for future global quantum network based on satellite-ground quantum communications[8]. So far, the construction of China's quantum science satellite has entered Phase C.

## 3. Dark Matter Particle Explorer (DAMPE)

(1) Scientific objectives

DAMPE will investigate dark matter particle from deep space via high resolution observation of gamma-rays and electrons spectra and its space distribution. It will also help scientists study the transportation and acceleration of cosmic rays in the galaxy by measuring the energy spectra of heavy ions.

(2) International development status

The merging of two galaxy clusters observed by the Chandra X-ray Observatory in 2006 is regarded as a direct evidence for the existence of dark matter. Although the Fermi Gamma-ray Space Telescope, PAMELA and ATIC long duration balloon project all carried out space investigations on dark matter particles, they failed to directly prove the existence of dark matter particles due to limited observation accuracy[9]. In April 2013, the Alpha Magnetic Spectrometer (AMS-02) project announced that they observed an excess of positron rate in cosmic rays compared with theoretical expectation, which may indicate new scientific findings[10].

(3) China's foundation and progress

Chinese scientists have been actively engaged in dark matter research in recent years, and made some significant achievements in theoretical studies, numerical simulations, and experimental investigation based on international collaboration. For instance, a Chinese team worked with overseas partners to discover an excess of cosmic ray electrons at energies of 300–800 GeV via the ATIC project[11]. Now, the development of DAMPE is in Phase C.

## 4. Shijian-10

(1) Scientific objectives

Based on China's recoverable satellite technology, Shijian-10 will address China's microgravity science and space life sciences, promote the development of high technologies and stimulate breakthroughs in basic research in the nation.

(2) International development status

In the past three decades, numerous microgravity experiments have been carried out on manned spacecrafts, space stations and unmanned spacecrafts. In the late 1990s, the US, EU, Japan and other principal ISS members started their strategic in-orbit research on the basis of ISS. The research was generally concentrated on microgravity fluid physics and related frontier fields, including combustion science, materials science and biotechnology[12]. Lots of achievements have been made. For example, results of material tests were used to determine the degradation of polymers and solar-cell arrays in space environment, and glass forming metal alloys and metallic glass of great commercial value were developed on space shuttles.

(3) China's foundation and progress

Since 1987, China has completed many microgravity experiments based on recoverable satellites and Shijian series, including the Marangoni convection and thermocapillary convection of two immiscible liquid layers, the boiling heat transfer experiment, and the smoldering property tests of porous combustible materials. As one of the few countries with independent space science experimental capacity, China is playing an important role in relevant research in the world. In recent years, China has gained attention from foreign colleagues in microgravity fluid physics, space material science and space biomechanics with a series of research innovations[13]. Now the development of Shijian-10 is in Phase C.

## 5. KuaFu Project

(1) Scientific objectives

The Earth environment is sensitive to the variations of the Sun on different time scales. The study of space weather is to probe the solar variations, energy bursts and energy transmissions and to understand the physical laws about how the Sun influences the geospace environment.

The KuaFu project aims to carry out comprehensive and continuous explorations on space weather. Flying in front of the Earth, KuaFu A is responsible for the imaging and observation of the origin of solar winds and coronal mass ejections, and will trace the transmission, acceleration and heating processes of plasma substances in interplanetary spaces, so as to detect how the Sun drives the changes in the Earth's space environment. Consisting of two small satellites and based on international cooperation, KuaFu B focuses on the observation how the Earth's magnetosphere and atmosphere respond to solar winds and the resulting space weather effects. The KuaFu project will explore matter and energy transmission and the coupling process of the space system to greatly enhance our understanding of space weather.

(2) International development status

In the 1990s, scientists began to realize the importance of taking the Sun and the Earth as an integrated system for study. So far, more than ten artificial satellites have been launched into the space to observe physical processes of Sun-Earth connection. Represented by SOHO and Cluster/Double Star, these satellites have made notable breakthroughs in space weather research. The KuaFu project marks the beginning of an overall observation of the whole space weather system, which is vitally important for clarifying the cause and effect relationship of space weather.

(3) China's foundation and progress

The SOHO and IMAGE missions have laid a good foundation and pointed out a clear scientific frontier for KuaFu A and KuaFu B. However, China still faces several technical difficulties in the KuaFu Mission: (a) the high resolution, multi-spectral imaging of the corona transition region; (b) the imaging of the Sun and solar wind disturbances via energetic neutral atom technology; (c) the distinguishing and continuous imaging of auroral arcs in UV band in high polar orbits.

From the end of the *12th Five-Year Plan* to the *13th Five-Year Plan*, China will launch the above-mentioned space science satellites one by one. It will hopefully make important achievements and play a leading role in the world in quantum science completeness tests and in the study of black holes, dark matter particles, the kinetic properties of matter and rhythm of life in space environment, and the influences of solar bursts on the Earth system.

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# New-principle Aero-engine Prototype Is Expected to be Developed Successfully

An aero-engine is a high-tech product featuring high speed, light weight, high reliability, long life and cost effectiveness. It is reusable and resistant to high temperature and high pressure. Its R&D requires high cost, long time cycle, high technical hurdles and high industrial access condition. As a decisive factor of the performance of aircrafts such as winged missiles, unmanned aerial vehicles and fighters, the aero-engine plays a key role in modern warfare for the fight over air control and even the final outcome of a battle. Apart from that, the aero-engine is also an important foundation for the development of civil aviation and safeguards the efficiency and security of air transportation. The development of the core technologies of aero-engines is not only highly relevant to a country's national security, its people's livelihood and position in the world, but also stands for the development degree of that nation's science, technology, military power and comprehensive strength. Therefore, it is an urgent task for China to develop its own new-principle aero-space engine and narrow down its gap with world leaders in aero-space technologies[1].

### 1. Thrust-to-weight ratio: the most important performance indicator for aero-engines

The thrust-to-weight ratio is the ratio of an engine's thrust to its own weight. The ratio directly impacts the maximum flight speed, ceiling, task load and maneuverability of a military aircraft, and thus is the most important integrated indicator of an aero-engine. High thrust-to-weight ratio makes an ultimate goal pursued by aero-engine developers.

The international standard for the fourth-generation fighter, which features supersonic cruise capability, stealthiness, super maneuverability and information superiority, should be equipped with an engine with a thrust-to-weight ratio of around 10.

The existing aero-engines widely recognized to have a thrust-to-weight ratio of around 10 include: the EJ200 turbofan engine jointly developed by European countries, the M88 series of turbofan engine developed by France, the AL-41F turbofan engine developed by Russia and the F119, F120, F135 and F136 engines developed by the United States[2]. However, only the US engine series practically serve on fourth-generation fighters.

The United States launched the "Integrated High Performance Turbine Engine Technology" (IHPTET) plan in 1988 and a follow-up plan on "Versatile Affordable Advanced Turbine Engine" (VAATE) in 2005. The IHPTET plan aimed at doubling the engine's thrust-to-weight ratio, but the actual result was an increase by only 70% when the plan ended in 2005. VAATE, to be completed in 2017, has several specific targets for the new engine: 200% increase in thrust-to-weight ratio (to around 20) as compared with that in 2000, 25% reduction in fuel consumption, 60% reduction in life cycle cost, and a tenfold increase in economic affordability over the F119 engine. However, by far, the VAATE plan has failed its target for a thrust-to-weight ratio of 16 by 2010. Meanwhile, in order to compete with the US, scientists from Britain, Italy and Germany together participated in the second phase implementation of the "Advanced Core Military Engine" (ACME-II) program. Britain and France jointly enforced the "Advanced Military Engine Technology" (AM-ET) plan, and NATO and Russia also proposed a similar scheme and the goal to develop a high thrust-to-weight ratio aero-engine[3]. However, all these programs seem to face enormous difficulties in achieving their targets, especially the thrust-to-weight ratio targets. Therefore, there is an urgent need to explore new principles, methods and technologies and break current technical bottlenecks to substantially improve the overall performance of aero-engines in the world.

### 2. China's third and fourth generation aero-engines under development

The development route of aero-engines in China has gone through imitation and amelioration to independent R&D in recent years. In 2002, China finalized the design of its first turbojet engine "Kunlun". In 2003, the turbofan engine "Qinling" completed domestic production and passed technical evaluation. In 2004, an improved turbojet engine was stereotyped and put to industrial production. At present, China is working on "Taihang" and a fourth generation military turbofan engine with targeted thrust-to-weight ratios at around 8 and 10, respectively. Among them, "Taihang" will be the nation's first self-developed third generation turbofan engine (design finalized in 2006), and the research on the fourth generation turbofan engine has achieved significant progress by far[4].

### 3. R&D progress of new-principle aero-engine

Besides traditional turbojet and turbofan engines, a variety of unconventional aero-engines have been developed around the world, including the pulsed detonation engines (PDE) for supersonic cruise missiles and unmanned aerial vehicles (Mach 0–5), the supersonic combustion ramjet (Scramjet) engines for hypersonic cruise missiles and space aircrafts (Mach 6–25), and combined cycle engines such as the turbine-based combination cycle (TBCC) and rocket-based combination cycle (RBCC). When the pursuit of speed is an eternal dream of human, the hypersonic propulsion system has triggered "the third revolution" in world's aviation propulsion history after propellers and jets.

Studies in this regard have been going on for many years in countries like the United States, Russia, Britain, France, Japan and India. To name a few projects or plans: X51A, HyFly, HTV, Needle, VLL-expert, Skylon and HAHV. The X51A of the US, equipped with a scramjet engine, performed four flight tests and achieved a maximum flight speed of 5.1 times the speed of sound, which failed its design speed of six times the speed of sound. The HyFly project mainly involved the technologies for a sub-burning and super-burning dual-mode ramjet engine, but unfortunately it failed all three flight tests and the technological test and demonstration. In the HTV project, the propulsion system of the demonstration engine of the Blackswift technology composed of two TBCC fueled by JP-7 hydrocarbon. But with the cancellation of the Blackswift project in 2009, the development of this kind of propulsion system also came to a standstill. In a word, the development of unconventional aero-engines has not been successful around the world.

In China, many scientists from universities and academic institutions have conducted research on unconventional aero-engines, and some work has led to a theoretical or engineering prototype.

Quite different from the above mentioned unconventional aero-engines, China is also working on a new-type aero-engine based on novel pressurization principle developed by domestic scientists, which will effectively improve the aerodynamic performance and structural design of the compression system and promote the engine's thrust-to weight ratio. It is very likely that China will succeed in developing this new-principle aero-engine and giving the world's first demonstration of a prototype engine with thrust-to-weight ratio over 15.

## 4. Breakthroughs to be expected

The development of aero-engine technologies is embracing a historic opportunity in China. After 60 years of endeavor, the country has gained a substantial technical and material basis on aviation engine technologies, strong testing and manufacturing capability, as well as a team of well-qualified science workers. China's ever-improving industrial base is rendering more R&D funding and infrastructure support to its aviation industry. Moreover, to strengthen national air power and cure the "heart disease" of China's aircrafts, top decision-makers have decided to include the development of aero-engines in the national key high-tech projects and probably as a national priority program.

But we must be aware that the aero-engine technology is a multi-disciplinary and very complicated scientific and technological system. Compared with developed countries, China still lags far behind and has a long way to go, especially in strengthening its industrial base, upgrading its management mode and gaining a more thorough understanding of its research and development patterns. China faces severe challenges in catching up with the world in aero-engine development.

An analysis of domestic and overseas progress tells us that China should enhance basic research in the field and explore a different technical route with the rest of the world. Through in-depth analysis, we found that turbo machinery, the most important and massive part of an aero-engine, has large potential in technical improvement from the viewpoint of aerodynamics. In other words, we can use a new supercharging method to drastically improve the single-stage pressure ratio, reduce the number of stages and the length of the compression system, and thus considerably increase the engine's thrust-to-weight ratio under the same thermodynamic environment. We should deepen fundamental research, develop better pressurization and flow control theory of the compression system, and gradually form a fundamental research system for aero-engines. Specific attention should be paid to solving issues like the compression-boosting mechanism, the mechanism of the unsteady interference in the inter-stage turbo machinery, etc. The key technological problems to be addressed include: the aerodynamic performance and structural design methods of the compression systems, the matching mechanism of the engine parts, the hot end fluid-solid thermal coupling technology and the multi-variable engine control technology, the efficient and high-performance computing methods and testing techniques as technical reserves, and a new aero-engine technology system with high thrust-to-weight ratio.

Once the aero-engines with high thrust-to-weight ratio have been successfully developed in China, they will be able to safeguard China's high-speed cruise missiles, high-performance fighters and near-space vehicles, and alter China's backward situation in the field. In the long run, breakthroughs in aero-engine technologies will effectively promote the upgrading of China's fighters, boost a huge leap in their performance, and enhance the nation's position as an aviation power. Thanks to the sustained economic growth, thriving trade activities, increasing personal wealth and striding liberalization of the market in China, its civil aviation industry is about to prosper, and technological breakthroughs in high-performance aero-engines with independent intellectual property rights will make more economic contribution to China's civil aviation industry.

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# China's Manned Submersible and Deep-sea Exploration Technologies Will Achieve Leapfrog Development

Since the 20th century, technologies for outer space exploration have developed rapidly, but we still know little about the deep sea on Earth. "We know even less about the deep sea than the Moon or Mars", Professor WANG Pinxian from the Chinese Academy of Science once remarked. It means that we are on a relatively low level of scientific research about the deep sea, but it also indicates a huge potential in the field.

## 1. The manned deep-sea submersible will guide the development of deep-sea exploration technologies

The deep-sea exploration technology is a complicated and integrated set of high technology that involve many S&T disciplines and can provide methods and instruments for the scientific research and resources exploration of the deep sea. It can also promote the development of a variety of general technologies and equipment concerning deep sea exploration. The technology is an essential means to detect resources in the deep blue, a foundation for the development of oceanography, and a stimulus for progresses in related fields.

In general, instruments for deep sea exploration include: drilling ships, various deep-sea probes, ocean observatories, and unmanned deep-sea submersibles (ROV and AUV) and manned ones (HOV). Among them, the HOV plays an irreplaceable role thanks to its human-machine interaction nature, and is an indicator for a nation's deep sea exploration level. To some extent, the HOV is a role model of the state-of-the-art detectors like manned spacecrafts.

Since the 1970s, HOVs have become an important tool and found wide application in ocean exploration. It is instrumental in deep-sea oil exploitation, oceanic civil engineering, the construction and maintenance of submarine cables, submarine rescue, military reconnaissance, etc.[1] Generally speaking, an HOV consists of the following components: the pressure hull with a life support system, the balanced propulsion system that controls the submersible's rising, descending and posturing, the storage batteries, the communication and navigation system, the joy stick, the lighting facilities, the observation port and the streamline framework[2]. HOVs can carry a lot of scientific equipment for seafloor observation, resources exploration, sampling, and in situ experiments. Compared with ROVs and AUVs, HOVs have a distinctive advantage that it can fully utilize the human brain's real-time observation and analysis abilities to process observed images and scenes, and at the same time make timely responses.

## 2. The current status of manned deep-sea submersibles in the world

At present, five countries in the world, namely the United States, Japan, France, Russia and China are capable of developing manned deep-sea submersibles.

With leading deep-sea submersible technologies, the United States built the world's first deep-sea submersible capable of carrying passengers (Alvin) in 1964. After the first phase of upgrading, the Alvin can now reach the depth of 4,500 m. After a second upgrading, it is expected to go down to the depth of 6,500 m and explore over 99% of the sea areas in the world. The US has also built the Pisces IV and Pisces V submersibles with maximum diving depth of 2,000 m.

Shinkai 6500 was a deep-sea submersible developed by Japan in 1989. Its highest diving record is 6,500 m, the world record before China's Jiaolong reached 7,000 m beneath. Shinkai 6500, 9.5 m long and 2.7 m wide, can stay under water for up to eight hours at a time and has carried out more than 1,000 dives by far.

Russia has two 6,000 m manned deep-sea submersibles, MIR-1 and MIR-2, which were built in 1987. The two submersibles are equipped with a lot of instruments to monitor deep-sea parameters and submarine geography, and can stay under water for 20 hours. In 2011, Russia built another two 6,000 m deep-sea submersibles to provide sustaining support for deep-sea exploration.

The Nautile built by France in 1984 can reach a maximum depth of 6,000 m. By far, it has completed over 1,500 dives and various tasks such as archaeological research, polymetallic nodules exploration and deep-sea ecological research.

China's manned submersible Jiaolong can dive to the depth of over 7,000 m. It is one of the most advanced manned submersibles in the world and is of vital strategic importance to China.

## 3. Possible breakthroughs in the future

There are still several key technical difficulties to be solved for the future of manned deep-sea submersibles. They include:

*(1) High intensity, pressure proof materials for the hull.* The choice of pressure proof materials for the hull of a manned deep sea submersible is important because it determines the submersible's weight. The traditional materials are steel or titanium alloy. The former is of high

density, which hinders the submersible's control of rising and descending[3]. The latter is too expensive for wide application. Therefore, the development of alternative materials with superior performance and low cost is the key to the future of manned deep-sea submersibles.

*(2) Technologies for high capacity batteries.* The capacity and discharge ability of a battery is crucial for the submersible's cruise performance, so batteries with high capacity and moderate cost are also very important for deep-sea submersibles.

*(3) Application of high definition observation instruments.* Observation instruments are a submersible's eyes. With the continuous upgrading of high definition photograph technology in recent years, it becomes possible to build a high definition observing system on submersibles. By equipping a submersible with the most advanced cameras, its working capacity can be greatly promoted.

*(4) Integration of advanced working tools.* A deep-sea submersible's working capacity depends not only on its diving depth but also on its operational capability. Various instruments should be integrated and installed on a submersible for it to carry out multiple tasks in the extreme deep-sea environment. Expanding the function of a deep-sea submersible's ports is one way to improve the submersible's working capacity.

## 4. Possible impacts brought by manned deep-sea submersibles

The manned deep-sea submersible technology will exert a profound influence on global ocean resources exploration. As an extremely comprehensive technology, it can also boost the advancement of related technologies.

Resource shortage has become a global issue in today's world[4]. With a pending exhaustion of terrestrial resources, the exploitation of the deep sea is just around the corner, which covered up to over 90% of the entire ocean area[5]. The deep sea is the home to abundant polymetallic nodules, rich cobalt crust, flammable ice and other resources, whose total amount may come to as much as dozens or thousands times of those on the land[6]. It is very important to use manned deep-sea submersibles for detailed seafloor resources exploitation. In recent years, countries like Japan and the United States have devoted a lot of efforts to explore and detect deep sea resources via manned submersibles, and they have achieved a series of significant discoveries. It is doubtless that once major technological breakthroughs are achieved, the world is to embrace a new global resources pattern.

The great opportunity rising from the deep ocean is of much significance to China. With the development of manned deep-sea submersible technology and other related technologies, the overall strength of China's ocean technology can be greatly enhanced. Thus, China should take Jiaolong as a new starting point and increase the support for deep ocean exploration and detection, so that its competitiveness will be considerably enhanced[7].

## 5. China's advantages

In June 2002, China set out to build its 7,000 m deep manned submersible. After ten years of hard work, its first manned deep-sea submersible Jiaolong was successful in diving to the depth of over 7,000 meters. It showed that China has become the fifth country in the world to obtain manned deep sea submersible technologies. Independently designed and developed by Chinese scientists and engineers, Jiaolong led the world in three aspects: (a) the state-of-the-art automatic navigation ability to cruise right above the seabed and the precise hovering and locating ability; (b) the unique high-speed underwater acoustic communication technology, which can transfer real-time voices, images and texts from the submersible to the mother vessel; (3) the oil-filled silver-zinc battery used on Jiaolong. Jiaolong will lead our study into the deep sea and facilitate the development of unmanned submersible technology and integrated deep-sea observation.

The Chinese Academy of Sciences plays a crucial role in the technical research and development of Jiaolong. Two of the above mentioned leading technologies were developed by scientists from the Shenyang Institute of Automation and the Institute of Acoustics, respectively. The R&D team from the Shenyang Institute of Automation used an advanced control strategy to effectively offset the uncertainty from the submersible, oceanic environment, etc. and realized the automatic cruise control function in long distance cruise. The acoustic system designed by the Institute of Acoustics provides Jiaolong with many important functions including communication, speed measurement, obstacles detection and topography survey[8, 9].

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# Breakthroughs in New Marine Technologies will Facilitate the Rapid Development of Blue Marine Economy

With the rapid economic growth and the increasing pressures on land resources, energy and space, the ocean will become one of the main areas of social and economic activities in future. Coastal countries and regions have attached great importance to the development of marine economy, and many countries are developing strategies to build themselves into sea powers through the research and development of marine science and technology. The Chinese government has also made up a strategic decision to build strong marine power through independent technological breakthroughs and to boost the rapid development of its marine industry.

## 1. New marine technologies can promote traditional marine industries and induce new ones

Since the 1960s, the large-scale and integrated new marine technologies have promoted the upgrading of marine industrial structure, which marks the rising of modern marine economy[1]. Technological breakthroughs in marine biology, marine resources detection and exploitation as well as marine environmental monitoring and remediation will drive new aquatic varieties, bio-products, devices, equipment and commodities to continue to emerge[2].

Aware of the importance of marine biotechnology for the utilization of marine bio-resources, coastal countries have increased their investment for the development of marine biotechnology[3-7]. For instance, the transgenic technologies for animals (especially fish) were very well developed long ago, but their safety issue has been questioned by many people. For instance, a variety of transgenic fish which grows two times faster than its natural counterpart entered the legal procedure for market access in the United States 17 years ago, and went through repeated debates before finally passing the verification on food safety and environmental safety, and it is very likely to become the world's first edible transgenetic animal admitted to the market. In 2010, the European Science Foundation estimated in a report that Europe can become a world leader in marine biotechnology within ten years, and that marine biotechnology represented a 2.8 billion euro market globally with potential to grow up by 12% annually[8]. New technologies such as genome-wide sequencing, structural and genetic analysis, the application of biotechnology, the extraction and purification of DNA and the automation of molecular analysis have greatly enhanced the research level and expanded the application of marine biotechnology, and will fundamentally change the structure of traditional marine industries and promote the emergence of new industries for the more effective, sustainable development and utilization of marine bio-resources.

New marine technologies, represented by the deep submergence technology, are pushing forward the exploration and utilization of deep-sea marine resources. The development and application of integrated systems and core technologies including multi-functional cable controlled underwater robot, high-precision underwater autopilot, deep seabed observation system and deep-sea space station will provide support to the comprehensive exploitation and utilization of deep sea resources. By far, four countries including the United States, Japan, South Korea and China have managed to obtain combustible ice (gas hydrates) samples from the deep seabed, and Japan claimed that it has mastered the large-scale mining technology for combustible ice. As China's strategic focus on marine science expands from the offshore to the ocean and from shallow water to deep sea, its deep-sea exploration technology are expecting historic breakthroughs.

Upon the continuous depletion of fossil fuels and the need to cut carbon emissions today, renewable marine energy including wave energy, wind energy, salinity gradient energy and marine biomass are playing an increasingly important role in the alternative energy strategy. Many countries and organizations have worked out development programs and technology roadmaps to strengthen research and development in this regard, and led to breakthroughs in ocean power generation technologies, especially in Britain, Denmark and Sweden where ocean power generation is already in commercial operation. Among the five innovative energy technologies to help human reduce reliance on fossil fuels, as reported by the *Economist* magazine on its website, one is about algae bio-fuels. Study showed that every acre of algae could produce thousands of gallons of gasoline, while crops cultivated on the same size of land can only produce hundreds of gallons of gasoline. The merge of different disciplines, the combination of science, technology and engineering, as well as the close collaboration of the government, industry, university, academics and military have become the key to sharpen a nation's competitive edge in marine technology and innovation.

### 2. New marine industries are developing rapidly to become a new economic growth point

In the past 30 years, the world's output of marine economy has witnessed a rapid increase from less than 250 billion US dollars in 1980 to 4.5 trillion in 2009. The new marine industry is the fasted growing industry in global marine economy in the past decade, with an average annual growth rate at about 28%. Among that, marine biomedicine grows by 39%, seawater utilization by 33% and marine power generation by 24%[9].

For China, from 2003 to 2012, its gross marine production increased from about one trillion yuan to about five trillion yuan with an average annual growth of 19.88%. From 2007 to 2012, the annual growth rate of China's strategic new marine industries exceeded 20%. Among these new industries, marine bio-medicine, seawater utilization and marine-based renewable energy power generation enjoyed relatively high industrialization level and a growth by 73.7%, 10% and 42.9% compared to 2011, respectively, much faster than the growth of traditional marine industries. It is estimated that during the *12$^{th}$ Five-Year Plan* period, the contribution of science and technology to marine economy will rise to 60%.

However, for the moment, the dominate industries in China's marine economy are still traditional marine fisheries, marine transportation and coastal tourism, while the technology-intensive industries (such as offshore oil and gas exploration, marine mining, marine bio-medicine, seawater utilization and electricity generation) still account for a very small portion in terms of output. It indicates that China's new marine industries are still underdeveloped. With the development of marine technologies around the world, China is expecting a historic opportunity to boost its emerging marine industries.

### 3. Development of marine technologies in China and China's advantages

Thanks to the development of science and technology in China for over 60 years, the nation has achieved remarkable progress in marine sciences, such as biological oceanography, marine ecology, marine chemistry and marine environmental sciences. They have provided scientific guidance to marine fisheries, oil and gas exploitation, marine environmental protection and disaster prevention and mitigation, and led to the establishment of a preliminary marine sciences research system with regional and interdisciplinary characteristic. According to *China Marine Statistical Yearbook 2011*, in 2010, China hosted 181 marine research institutions and 29,676 scientific workers in marine science, who have been playing an active role in the global marine science community.

Over the past decade, Chinese scholars have conducted scientific cooperation with colleagues from 55 countries and regions around the world in marine sciences. They have jointly published over 1,000 *SCI* papers, and the number is on the rise every year. The collaborators mainly come from the United States (544 co-authored papers), Japan (136 papers), Australia and Canada (94 papers for each), and the most active domestic research institutions include the Chinese Academy of Sciences (135 papers), the Ocean University of China (100 papers), Xiamen University (68 papers), the State Oceanic Administration (57 papers), Shanghai Ocean University (40 papers) and the Hong Kong University of Science and Technology (38 papers).

China has been making leaps and bounds in marine technologies in recent years. The manned submersible Jiaolong dived to 7,062 m depth beneath the sea, which marked a major technological breakthrough in China's deep-sea scientific survey and resource exploitation, enabling China to become a world rival in the field. Since the 1980s, China has carried out 28 expeditions to the Antarctic and five to Arctic regions, under a strategic deployment which involves the construction and operation of one research vessel ("XueLong"), four stations (the Great Wall Station, Zhongshan Station and Kunlun Station in the Antarctic and the Yellow River Station in Arctic regions), and the Chinese Polar Expedition Domestic Base[9]. With the melting of Arctic sea ice and the opening up of summer waterway, China has a bright future in exploiting oil and gas resources in Arctic regions. Also, with the launch of a new research vessel named "Kexue", China is now owner of a world-leading mobile lab and platform in deep sea science. In terms of equipment construction, in recent years, China has achieved a large number of major independent innovations in the development and manufacturing of marine engineering equipments, such as deep-water semi-submersible drilling platforms and jack-up drilling platforms. On May 9, 2012, China's first world-class sixth generation deep-water semi-submersible drilling platform was put into operation in the South China Sea. On August

28, 2013, the first jack-up rig platform built in Shanghai was launched for commissioning. This platform of JU-2000E type is mainly used for the detection and exploitation of offshore oil and gas, indicating that another high-tech and high value-added marine engineer project had entered final assembly stage[10]. As for new marine energy technologies, China is taking the lead in the exploitation of tidal energy and tidal-current energy, with generally mature wave energy technologies and relatively weak thermal energy technologies. Although China is a latecomer in maritime wind energy, its development has been very rapid in these years and has formed a maritime wind energy industry of certain scale.

## 4. Bottleneck problems to be solved

Worldwide speaking, the advantage of marine economic powers largely comes from their sound policies, regulations and the heavy investment in marine industries. In China, although the State Oceanic Administration has initiated a plan on the strategic development of marine industries, but a good social atmosphere has yet to form for all people to participate in and support emerging marine industries. Meanwhile, the sound development of emerging marine industries relies heavily on preferential policies and strong investment from the government. China should actively explore and push forward a diversified investment mechanism that combines government investment, business investment and foreign investment under market economy. Compared with other industries, marine industries like marine medicine, seawater utilization and deep-sea mining are highly dependent on high technologies[11]. For example, an important goal for the development of marine biotechnology is to convert candidate genes into bio-products, metabolites into leads and drugs, biological matrix into biological materials/devices, and biomass into bio-fuels [12]. From marine science to marine technology and marine industry, high-technology is a main line to stick to and follow through future development. The science-technology integration and the technology-economy integration are another two major issues to be addressed in the future. On the whole, China's independent R&D on marine technologies is still weak, especially in equipments, manufacturing and the lower domestication rate of critical components and materials. So theoretically there is a lot of room for China to improve its marine technologies.

Constanza estimated in 1997 that the value of global marine ecosystem is 20.949 trillion US dollars per year, among which the coastal ecological value is 12.568 trillion dollars annually[13]. *Charting the Course for Ocean Science in the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy*, which was issue in 2007, identified marine ecology as a research priority for human welfare. NOAA's *Next-Generation Strategic Plan (2010)* regarded "healthy oceans", meaning marine fisheries, habitats and biodiversity sustained within healthy and productive ecosystems, as an important strategic objective. The Chinese government has also taken the construction of marine ecological civilization as a key development goal. However, the strategic focuses and development priorities of the restoration and promotion of China's marine ecosystem still need to be defined and clarified.

With the rapid development of marine economy, it is very important to train top-notch scientists and management personnel for marine sciences. In China, workers engaged in marine science and technology has been increasing year by year, but in areas like marine biomedicine, marine electricity and seawater utilization, the number of high-caliber talents is still far from enough, especially talents who are good at technology transfer. Therefore, the recruitment and training of talents makes an important solution to promote breakthroughs in marine technologies and to boost the development of marine industries in China.

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