Major World S&T Events for the Next Decade

A major S&T event in the world refers to an S&T activity and its achievements with worldwide influence, including:

1. A transformative breakthrough in fundamental scientific understanding, which gives rise to systematic S&T innovation, and multiple technological innovation clusters, such as the discovery of electromagnetic induction and the establishment of electromagnetic theory;

2. Discovery of phenomena unexplainable by the existing theoretical system, like blackbody radiation discovery gave birth to quantum mechanics;

3. A transformative technological breakthrough triggering industrial innovation or the development of major tools, which effectively overcomes the restraints of energy, resources and the environment, improving people's health and with major impact on people's productivity and lifestyles, like the industrial revolutions made possible by the steam engine and computers, and the medical revolution caused by antibiotics;

4. Human activities breaking major limits, such as manned moon landings.

From a comprehensive point of view, it is possible the following 22 major S&T events might take place in the next five to 10 years.

Confirming of the Higgs Boson

1. Significance of the search for the Higgs boson

General relativity and the Standard Model are two major theories in modern physics. General relativity describes space, time and gravity, while the Standard Model is a theory concerning the electromagnetic, weak, and strong nuclear interactions. The Standard Model divides particles into the two categories of fermions (including quarks and leptons) and bosons (including gluons, photons, W and Z bosons and the Higgs boson) according to their spin. According to the Standard Model's predictions, there are a total of 61 particles in these two categories[1]. All the particles but the Higgs boson have been experimentally supported and validated. The Higgs particle is a boson with no spin or electric charge, it has mass and is very unstable. It is the foundation of the Standard Model. Therefore, if the Higgs boson does not exist, the Standard Model will fail. In addition, the Higgs boson is considered to be the source of the mass of elementary particles. If the Higgs boson exists, it would be well explaining why some elementary particles have mass while others don't.

It is extremely difficult to hunt for the Higgs boson. The Higgs has large mass that requires high energy to produce, so an expensive super particle accelerator with high energy is needed. However, even as the Higgs is produced, it will decay into other particles in a nanosecond, making it difficult to detect. Therefore, physicists use detectors of very high precision to collect photoelectric signals, in the hope of finding out signals of the Higgs from vast amounts of data and detecting trajectories through a series of complex mathematical operations, thereby demonstrating the existence of the Higgs.

2. Progress in the search of the Higgs boson

The Higgs boson is named after Peter Higgs, one of physicists who proposed the mechanism that suggested the existence of such a particle in 1964[2,3].The experimental search for the Higgs boson began in the early 1980s, after the European Organization for Nuclear Research (CERN) discovered the W and Z bosons and confirmed the theoretical expectations. After a lot of experiments, physicists greatly excluded the range of the mass of Higgs boson. In the mid-1980s, CERN built a 27 km-long Large Electron-Positron (LEP) collider aiming at Higgs bosons with masses slightly higher than 100 GeV. Meanwhile, US physicists proposed to build an enormously expensive Superconducting Super Collider (SSC) for creating Higgs bosons with masses up to 1 TeV. However, the SSC was closed by the US Congress in 1993 and the budget at that time exceeded 10 billion US dollars[4]. The top quark with a mass of approximately 174 GeV was discovered at Fermilab in 1995, which, according to the Standard Model, implied that the Higgs mass should be less than 200 GeV. In the late 1990s, the LEP operated at an energy exceeding its design value 200 GeV, but physicists still failed to find any evidence for the Higgs in the four detectors. In 2000, the ALEPH experiment, one of the four LEP experiments, detected signs of a new particle around 115 GeV, but no significant signal was shown for the other three LEP experiments. Soon, the LEP collider was shut down, and the 10-year construction of the Large Hadron Collider (LHC) started.

After the shutdown of the LEP collider, Fermilab stood supreme. However, until its permanently shut down in September 2011, the Tevatron collider at Fermilab had made no major new discoveries due to its energy and luminosity except excluding masses from 156 GeV to 177 GeV[5].

The LHC began taking data in 2010. The ATLAS experiment and the CMS experiment are the two LHC experiments exploring the Higgs boson. In 2011, several work narrowed down the range of the Higgs mass to 115–130 GeV[6]. In July 2012, CERN announced that ATLAS and CMS had discovered a new 125–126 GeV[7,8] boson at a 5σ confidence level (namely 99.99994% confidence, a criterion for discovery of new particles). CERN named the particle "Higgs-like particle". In March 2013, ATLAS and CMS experiments announced that the particle "is looking more and more like a Higgs boson" after analyzing more data[9].

Nevertheless, more data is needed to determine whether the Higgs boson exists. The energy of LHC will double after its upgrade in 2015, which will lead to more collisions and data to help confirming and further understanding the Higgs boson.

3. Role of Chinese scientists

Chinese scientists have participated in the ATLAS and CMS experiments since 1999, with the funding from the Ministry of Science and Technology, the National Natural Science Foundation of China and the Chinese Academy of Sciences. The institutions in the ATLAS experiment include the Institute of High Energy Physics, University of Science and Technology of China, Nanjing University, Shandong University and Shanghai Jiao Tong University. And the institutions involved in the CMS experiment included the Institute of High Energy Physics, Peking University and Shanghai Silicate Research Institute of the Chinese Academy of Sciences.

Chinese scientists have made significant contributions to the discovery of the "Higgs-like particle". In the ATLAS experiment, important components of the liquid argon electromagnetic calorimeter and precision drift chambers for the muon system, testing of the electronics of the trigger system, as well as part ofthe grid computing system are made by scientists from Nanjing University, the Institute of High Energy Physics, the University of Science and Technology of China, etc. Shandong University contributes in constructing more than 400 Thin Gap Chamber (TGC) detectors. Chinese physicists made noted contributions towards the data analysis leading to the discovery of the Higgs boson by the ATLAS experiment. Specifically Chinese physicists studied photon trigger efficiency and backgrounds to the Higgs to two photon final state, managed data production for the $H\rightarrow ZZ^*\rightarrow 4l$ measurement, determined the event selection and developed data driven evaluation of Z+jet background to the Higgs signal[10].

In the CMS experiment, Chinese scientists have also made important contributions. One third of the end-cap muon detectors and all the crystals in end-cap electromagnetic calorimeter were developed and provided by Chinese scientists. In particular, the proposal of the CMS Chinese team was adopted to discriminate signal and backgrounds with the method of multivariate analysis; the sensitivity of Higgs boson searches thus increased by 3%.

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Neutrino Oscillation Experiments Hopeful to Accelerate the Delivery of Solutions to the "Mystery of Missing Antimatter"

1. Neutrino research occupies an important position in particle physics

In 1930, Austrian physicist Pauli[1] proposed the neutrino hypothesis to explain the loss of energy in the process of beta decay. But since neutrinos are uncharged and nearly massless (less than one millionth of the electron mass) and rarely interact with other matter (interact via only the weak force and gravity), they are very difficult to detect. For that reason, for a long time, neutrinos only appeared in the equations of theoretical physicists and experiments had failed to confirm their existence. In 1934, Italian physicist Fermi proposed the theory of beta decay that incorporates the neutrino, which was quantitatively consistent with experimental data. In 1941, Chinese physicist WANG Ganchang published the article Suggestions on the Detection of the Neutrino in the U.S. journal *Physical Review*. An experiment conducted by the American physicist J. Alan on the basis of WANG Ganchang's scheme confirmed the existence of neutrinos in 1942. In 1956, American physicist F. Reines et al., using a nuclear reactor as a strong source of neutrinos, experimentally observed neutrinos (electron antineutrinos) directly for the first time, and won the 1995 Nobel Prize in physics for that.

The Nobel Prize has been awarded for research in neutrino physics three times in history; moreover, this will become a very active area of research in future. Competition in accelerator neutrino experiments, atmospheric neutrino experiments and reactor neutrino experiments will become increasingly intense. Existing large-scale programs include the T2K experiment in Japan and the NOvA experiment in the United States, while more are under planning, such as the JUNO experiment in Jiangmen, China, the LBNE experiment in the United States, the PINGU experiment at the South Pole, the Hyper-K experiment in Japan and the INO experiment in India. The scientific community is looking forward to more brilliant achievements. Throughout the course of scientific development, every major discovery in fundamental science would trigger a new leap in technology. Scientists have already begun to look forward to exploring the prospect of neutrino communication and Earth neutrino tomography that uses neutrinos to explore the geological structure of the Earth's interior. Breakthroughs in theoretical particle physics and cosmology to be brought about by neutrino research and their impact on society, economy and culture may go beyond people's imagination.

2. Neutrino oscillation has become a central issue in neutrino research

In the 1960s, neutrino research entered a new phase. In 1962, American physicists Lederman, Schwartz and Steinberger proposed using an accelerator to produce neutrinos, which led to the discovery of a second type of neutrino: the muon neutrino. This outstanding discovery verified the doublet structure of the leptons, laying the foundation for the establishment of the electroweak unification theory, and thusly won the 1988 Nobel Prize in Physics. In 1957, former Soviet theoretical physicist Pontecorvo first put forward the "neutrino oscillation" hypothesis, proposing that neutrino-antineutrino transitions may occur under certain conditions. Limited by historical conditions, this idea was not accurate, but it has led to the modern theory of neutrino oscillation: if a neutrino mass is not exactly zero, and the mass eigenstates of the neutrino are different from the weak interaction eigenstates, then according to the principles of quantum mechanics, transitions may take place between neutrinos of different types. This is also an approach to determine whether neutrinos have a mass of zero. Neutrino mass has become a key issue in the study of neutrinos. The standard model of particle physics assigns zero mass to neutrinos, therefore, non-zero neutrino mass will lead to new physics beyond the standard model. In 1968, American scientist R. Davis discovered the phenomenon of "missing" solar neutrinos, that is, only 1/3 of the expected number of solar neutrinos were detected on the Earth. The cosmic ray experiment (1960s) in India, IMB experiment in the United States and the Kamiokande experiment in Japan (1985) discovered the atmospheric neutrino anomaly. Japanese Kamiokande detector detected neutrinos from supernova SN1987A (1987). In 1998, the Super-Kamiokande experiment (Super-K[2]) led by Japanese physicist Masatoshi Koshiba confirmed atmospheric neutrino oscillation. In 2000, Fermilab discovered a third type of neutrino: the tau neutrino. The SNO[3] experiment in Canada (2001) and the KamLAND[4] reactor experiment (2002) in Japan further confirmed solar neutrino oscillation; in 2002, the accelerator neutrino oscillation experiment in Japan K2K confirmed the atmospheric neutrino oscillation. Davis and Koshiba were jointly awarded the 2002 Nobel Prize in Physics for their outstanding achievement in the detection of cosmic neutrinos. This achievement had given rise to neutrino astrophysics, opening up a new “window” on observations of the universe. As a new means of astronomical observation, neutrino detection technology has become a new “probe” in the study of early formation of the universe, supernova explosion, stellar structure and evolution, and cosmic dark matter.

3. The Daya Bay neutrino experiment puts China on the cutting edge of particle physics research

Around 2003, the phenomenon of neutrino oscillation was firmly established through a multitude of experimental evidences. Associated with neutrino masses, neutrino oscillation has become a central issue in neutrino research. Previously discovered neutrino oscillation can be grouped into two categories: atmospheric neutrino oscillation and solar neutrino oscillation. There are three unresolved issues concerning neutrino oscillations: looking for the third type of oscillation ($\sin^2 2\theta_{13}$), determining the mass hierarchy (sign of Δm^2_{32}) and the symmetry breaking (δ_{CP}). Whether existing experimental techniques can be employed to study the latter two issues depends on the value of θ_{13}, so θ_{13} also determines the future direction of neutrino physics experiments. In 2003, the American Physical Society recommended the measurement of θ_{13} using reactor neutrinos as one of the top priorities in the neutrino oscillation studies. A total of eight experimental proposals were put forward worldwide, of which three were eventually put into practice, including the Double Chooz experiment in France, the Daya Bay experiment in China and the RENO experiment in South Korea. In 2003, researchers at the Institute of High Energy Physics proposed using the large number of neutrinos produced by the nuclear rectors of the Daya Bay Nuclear Power Plant to carry out a neutrino oscillation experiment and put forward an experimental scheme. Due to the large capacity (second in the world) of the Daya Bay Nuclear Power Plant and its favorable geographical conditions (near the mountains), the accuracy of the Daya Bay experiment is expected to be the highest worldwide, increasing the sensitivity of $\sin^2 2\theta$ measurement to 0.01. Measuring θ_{13} at Daya Bay represents a major opportunity for the development of particle physics in China. In 2006, the Daya Bay neutrino experiment was approved. It is currently the largest international cooperation project in the field of fundamental science in China, with a total investment of 170 million yuan from China and participation of scientists from China, the United States, Russia, and the Czech Republic. The results of the data collected from December 24, 2011 to February 17, 2012 showed[5] that the probability of the third kind of neutrino oscillation is 9.2% with an error of 1.7%, thusly discovering this new neutrino oscillation for the first time. The research finding was named among *Science* magazine’s top 10 breakthroughs of 2012[6], as the magazine commented, “if LHC researchers do not find new particles beyond those in the standard model, then neutrino physics could be the future of particle physics – as the fact that neutrinos even have mass isn’t part of the standard model. If so, the Daya Bay result may mark the moment when the field took off”. Co-spokesperson of the International Daya Bay Collaboration WANG Yifang said at a news conference that standing for a new understanding of the basic laws of the material world, this important research finding might determine the future development direction of neutrino physics and was also help to solve the “mystery of the missing antimatter”, namely the matter-antimatter asymmetry in the universe.

Daya Bay neutrino experiment took the lead in making a major breakthrough amid fierce international competition, putting China on the cutting edge of particle physics research. China is likely to occupy an important position in the global neutrino physics research in the next 10-15 years. The Jiangmen Underground Neutrino Observatory (JUNO, formerly known as Daya Bay-II) has zeroed in on the “mass ordering issue” and a number of major cutting-edge goals such as precision measurement of mixing parameters and detection of supernova neutrinos. Future accelerator experiments are also hopeful to solve the issue of measurement of “CP symmetry breaking”, which is related to the origin of matter in the universe.

There are many other unresolved issues concerning neutrinos. For example, whether the neutrino is a Dirac or a Majorana fermion, namely whether neutrinos are their own antiparticles is a fundamental issue in particle physics; absolute values of the neutrino masses are still unknown; measurement of the neutrino magnetic moment; the study of supernova neutrinos; the detection of neutrinos from the Big Bang, etc. They are likely to become cutting-edge and trendy research directions drawing attention from the fields of particle physics, astrophysics and cosmology, and so on.

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Prospects of Scientific Breakthroughs in Dark Matter Particle Detection and Related Research

1. As a key factor of the structure formation of the universe, the existence of dark matter has been widely accepted

"Dark matter" refers to a kind of matter in the universe which has gravitational effects, but has no direct interaction with light. It is deemed to be composed of completely new particles beyond the standard model of particle physics, however we know very little about the nature of dark matter.

At the beginning of the 20th century, the "two clouds" in physics sky – aether and blackbody radiation – overturned the classical physics theory and gave birth to quantum mechanics and the theory of relativity.

Similarly, dark matter, together with dark energy, are called the "two clouds" in the physics sky of the 21st century that will probably lead to a new revolution in physics and astronomy.

The concept of dark matter was first raised by a Swiss astronomer Fritz Zwicky. In 1933, Zwicky measured the velocity dispersions of galaxies in the Coma cluster. The galaxy cluster mass calculated by Virial Theorem based upon the measured galaxy velocity dispersions was almost 400 times higher than that deduced from the luminous stars in the cluster. Therefore, it was speculated that there might be non-luminous matter in the galaxy cluster. In the 1970s, more careful observations by the American astronomer Vera Rubin made the concept of "dark matter" recognized by the community. In 2006, Chandra X-ray Observatory observed a unique merger of two galaxy clusters and discovered distinct offset between the luminous and total mass distributions. It was deemed as direct evidence for the existence of dark matter[1]. In recent years, as a result of the precise measurements of cosmic microwave background radiation anisotropy by Wilkinson Microwave Anisotropy Probe (WMAP) and Planck satellite, we can precisely determine the matter contents in the universe by fitting the observational data. The latest result shows that dark matter accounts for 26.8% of the universe mass-energy components, and about 85% of the total matters[2]. From the day when the concept of dark matter was raised to the present, many evidences testifying to the existence of dark matter have been found in astronomical observations of different dimensions.

2. Various ways in detecting dark matter particles proposed, but so far no positive result obtained

As dark matter particles neither illuminate nor interact directly with light, it is impossible for common optical observations to find them. At present, there are roughly three kinds of methods available for detecting the dark matter particles:

(1) "Creating" the dark matter particles in collider and studying their physical properties. Though the "created" dark mater particles cannot be observed directly, whether there is a dark matter particle or not can be deduced from other particles observed. At the same time, in the process of "creating" a dark matter particle, some energy is taken away. Some properties of the dark matter can be deduced from the missing energy and its distribution. Up to now, no experiments at accelerators have definitely proved the existence of dark matter particles yet. The Large Hadron Collider (LHC) of the CERN that is being upgraded and restructured will be launched again in 2015. By then, the total collision energy of its proton beams will reach 14 TeV (trillion Electron volts). Hopefully a tiny amount of dark matter will be "created"[3].

(2) Direct detection. With this method, signals generated when dark matter particles collide with the nucleus in the detector will be detected directly. As the probability of collision is quite small, the signal to be generated will be "weak". To lower the background noise, the detector is usually placed deep underground. Direct dark matter particles detection experiment is the most important detection method for searching for dark matter

particles at present. With the present experiment precision, only the signal of weakly interacting massive particles (WIMP) can be detected, while the weaker signals such as the graviton's super-symmetric partner cannot be detected by this method. At present, dozens of international teams are designing experiments for detecting dark matter particles, such as XENON100 and Cryogenic Dark Matter Search (CDMS). Following the two events that were declared in 2009 to be possibly relevant to the dark matter particles, three more susceptible dark matter particle events were reported on April 13, 2013 by Super-CDMS. However, calculations indicated that the events are 99.81 percent more likely to be WIMPs than background fluctuations, which translates to approximately a three-sigma level of confidence. So, it won't be released as the evidence for dark matter particles[4,5].

(3) Indirect detection. It refers to the method to find the clues left by dark matter particles through measuring the energy spectrums of the stable high-energy particles from dark matter particle decay or annihilation, such as Gamma rays, positrons, antiprotons, or neutrinos. Affected by Earth atmosphere, it is quite difficult to conduct high-precision particle energy spectrum measurements on the ground. It is advised to conduct such experiments in the space. But, restricted by the observation precision, Fermi Gamma-ray Space Telescope, PAMELA and Advanced Thin Ionization Calorimeter (ATIC) failed to detect the definite dark matter particles. The key to space detection is to select the appropriate detection particle objects and the probe that is applicable to all kinds of particles, such as the large magnetic spectrometer. In April 2013, the international team running the Alpha Magnetic Spectrometer (AMS) which is the first space experiment with a precision of 1%, announced the first results in its search for dark matter. The AMS results are based on some 25 billion recorded events, including 400,000 positrons with energies between 0.5 GeV (giga electron volts) and 350 GeV, recorded over a year and a half. But, it is unknown whether the positron ratio comes from dark energy particles colliding with each other or from pulsars in our galaxy that produce antimatter[6,7].

3. It is expected that the detection of dark matter particles and related study will bring about a new revolution in physics

At present, major technology powers in the world have attached importance to dark matter particles detection and related study. For example, in March 2006 NSF-NASA-DOE Astronomy and Astrophysics Advisory Committee (AAAC) and the NSF-DOE High Energy Physics Advisory Panel established a Dark Matter Scientific Assessment Group (DMSAG) as a joint panel to advise NSF and DOE on matters concerning the U.S. dark-matter research program. It pointed out that the settlement of dark matter mystery is of great importance and that the U.S. must immediately double investment to maintain a leadership in the field. In 2008, EU launched Astroparticle Physics Roadmap Phase 1 and "What is the Universe made of? In particular: What is dark matter?" was ranked in the first place of the six basic questions to be emphatically settled in the next decade[8].

With the underground and ground large detectors and space detection experiments, it will surely be one of the most significant scientific discoveries of the 21st century to detect the dark mater particles and unveil the mystery of dark matter.

With respect to direct dark matter particles detection, experiments such as CDMS, XENON, ZEP-LIN and EDELWEISS are widely conducted in the world. What's more, the experiments sensitivity improves continuously. In this aspect, China has worked out a roadmap in 2008 and completed the world's deepest underground experiment lab — China Jinping Underground Laboratory, which is of great significance to direct high-precision dark matter particles detection and research. At present, the high-purity germanium based Chinese dark matter experiment (CDEX) of Tsinghua University and the liquid xenon Particle AND Astroparticle Xenon Observatory(PANDAX) experiment of the Shanghai Jiao Tong University are two direct dark matter particles detection experiments conducted by the lab in the first batch[9].

Regarding indirect dark matter particles detection, it is expected that more data will be generated in the forthcoming years through such experiments as the underground IceCube telescope covering 2,000 meters at the South Pole, High Energy Stereoscopic System (HESS) on the ground, or even the Very Energetic Radiation Imaging Telescope Array System (VERITAS), and Major Atmospheric Gamma Imaging Cherenkov (MAGIC). With the experiments upgrading and sensitivity improvement, in particular, the development of Large High Altitude Air Shower Observatory (LHAASO) in the future, the cosmic ray observatory of China will be of great potential in indirect dark matter particles detection. In respect of space detection, FERMI, AMS-02, China's Dark Matter Satellite and space station dark matter particles detection project will contribute to the dark matter particles research.

The research on dark matter properties is closely related to astronomical research. For example, the prediction or explanation of the signals of dark matter particles generated either from direct detection or indirect detection depends on the density and spatial distribution of dark matter. Therefore, both studies must be closely combined. In this aspect, it is expected that the U.S. Large Synoptic Survey Telescope (LSST) and Chinese Kunlun Dark Universe Survey Telescope at the South Pole will play important roles.

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Quantum Information Technology Will Lead the Next Generation of Information Technology

Quantum information science is a combination of quantum mechanics and information science, which transforms computing, coding, information processing and transmission process by the unique properties of quantum system, and develops new capabilities to process information more efficiently. It mainly includes two fields, i.e. quantum computing and quantum communication. The core objective of quantum information science is to develop real-world quantum computers and achieve long-distance quantum communication with absolute safety[1]. Current and future research focuses in quantum information science include quantum cryptography, quantum simulation and quantum measurement.

1. Global quantum communication expected to come true

After over 20 years of development, quantum communication has evolved from theory to experiment and is moving towards practical application. In recently years, quantum communication has undergone a leapfrogging development in terms of distance and speed, with communication distance exceeding 200 km. Some small and medium-scale quantum communication networks have been established, which have verified the feasibility of quantum networking, and begun to play a role in some information security fields (such as national security and finance).

In the quantum communication field, China has reached world's first-class level in many aspects. Metropolitan-scale quantum communication is ready for industrialization, and the industrialization preparation has reached an equal level with European countries and USA. The team led by Professor PAN Jianwei at the University of Science and Technology of China (USTC) is among the world's best in terms of long-distance quantum communication, quantum memory and quantum repeaters. For example, in 2012, PAN's team managed to realize a quantum memory with a read-out efficiency of 73% together with a storage lifetime of 3.2 ms, combining the best of two worlds[2]. Meanwhile, the Chinese Academy of Sciences (CAS) has launched a Strategic Priority Research Program entitled "Quantum Science Experimental Satellite", with the aim to launch a satellite for quantum science around the year of 2016. In 2012, this strategic piloting project successfully realized quantum teleportation and entanglement distribution over 100-kilometer free-space channels for the first time[3]. This will be a major step to the ultimate goal of high-speed satellite-to-ground quantum communication which will further connect the metropolitan area quantum communication networks on the ground[4].

The international competition will be more intense, as many countries will develop quantum secure quantum network with longer distance and larger scale, with emphasis on, for instance, quantum repeaters and satellite quantum communication. Scientists expect the global quantum communication to be realized in 10 years and it will generate profound impacts on human society in the next two or three decades. There are great application value and potential for quantum communication in sectors like military, national defense, finance, engineering and social utilities, etc.

2. Significant breakthrough expected in quantum computing

At present, standard quantum computing[5], measurement-based quantum computing[6], topological quantum computing[7] and adiabatic quantum computing have been experimentally verified on the premise of small amount of logic qubits[8]. Simple logic gate operation[9] and error correction[10] and some quantum algorithms have been demonstrated[11].

With respect to hardware, there is still no clear choice of the best physical system that will finally stand out. Superconducting qubits, cold atoms in optical lattices, and trapped ions etc. have their own advantages and challenges. A possible solution that meets all quantum computing requirements might be a hybrid system that integrates advantages from different systems. In 2012, PAN Jianwei and his team realized eight-qubit topological quantum error correction[12]. In 2013, the same team realized a quantum algorithm for solving linear equation systems on an optical quantum computer. In 2010, University of Innsbruck (Austria) created a 14-qubit entanglement using trapped-ion systems[13]. The University of Southern California (USA) proved that D-Wave Two quantum simulator developed by D-Wave Company (Canada) could demonstrate quantum annealing method[14].

In the next 5-10 years, a significant breakthrough is expected in quantum computation. The research efforts focus on superconducting qubits, trapped ions, optical lattices, integrated photon chips, and micro-nano structure materials for fully integrated quantum circuits[15].

3. Real-life application of quantum cryptography

In recent years, the United States, European Union and Japan, etc. have devoted huge resources to develop quantum cryptography technology[16] and made a series of achievements. China also takes the lead in this field. The first test on quantum communication was completed by Bennett, Brassard in 1989[17], in which the transmission distance via free space was only 30 cm. In 2004, NEC Corporation (Japan) declared a record of transmission distance of 150 km using optical quantum cryptography[18]. In the same year, GUO Guangcan and his team from USTC successfully realized point-to-point quantum key distribution between Beijing and Tianjin via a 125 km optical fiber[19]. Since the optical source used in these tests is attenuated laser instead of perfect single photon, the photon-number-splitting attack cannot be overcome and safe communication distance cannot exceed a range of 10 km.

The loophole caused by imperfect optical source can be efficiently overcome by decoy-state quantum communication technology, which extends the quantum key distribution to a safe distance exceeding 100 km. In 2007, decoy-state quantum communication technology was realized by the Los Alamos National Laboratory (USA)[20], University of Vienna[21] and PAN Jianwei and his team (China)[22] respectively, which laid the foundation for the metropolitan secure quantum communication. In 2012, PAN Jianwei and his team built world's first large-scale metropolitan area quantum communication network consisting of 46 nodes — Hefei metropolitan quantum communication network, which found its application in government departments, financial institutions, military enterprises and academic colleges and institutions in Hefei. Based on the mature large-scale metropolitan area quantum communication networking technology, PAN Jianwei and his team further applied the technology to the communication security assurance work for military parade celebrating the 60th National Day of China., the Financial Information Quantum Communication Verification Network under cooperation with the Xinhua News Agency and the Highly-secure Communication Support System Based on Quantum Communication providing information security assurance for the 18th national congress of the Communist Party of China .

In 2013, the thousand-kilometer large-scale optical quantum communication backbone network project "Beijing–Shanghai Backbone Line" was formally initiated (lead by PAN Jianwei and his team), which would connect the wide area optical quantum communication networks of Beijing, Shanghai, Jinan and Hefei. This is the first large-scale platform for quantum communication technology.

4. Significant breakthrough expected in quantum simulation

Quantum simulation is to mimic physical systems on an experimental platform for artificially-created quantum multibody system that are otherwise difficult to control and study in real experimental conditions, so as to gain qualitative or quantitative information of some unknown phenomena[23]. In 2009, PAN Jianwei and his team from USTC experimentally demonstrated a kind of exotic particle, anyonic, and its fractional statistics existing in two-dimensional space for the first time in the world by operating multi-photon entanglement state[24]. Using ultracold atom BEC, the team created norm potential and achieved "spin-orbit coupling" of ultracold boson[25]. In 2010, DU Jiangfeng and his team from USTC acquired ground state energy of hydrogen molecular with the manner of quantum simulation in nuclear magnetic resonance system[26] and simulated the dynamics of isomerization reaction in chemistry[27]. In 2011, a research team from Harvard University successfully simulated and detected one-dimensional antiferromagnetic spin chains with single-lattice imaging technology[28]. The rapid developing quantum simulation technology is approaching the limit that classical computers can simulate. Significant breakthrough is expected in the next 5-10 years. The current key issue is to develop qubit experimental platform with a certain scale and to develop practical solid quantum memory and other key components. As one of the most promising application fields of quantum computers, quantum simulation is expected to be realized earlier than general quantum computers[15, 29].

5. Emergence of quantum metrology

Quantum metrology is an emerging discipline in recent years. It breaks the standard quantum limits of classical measurements and is expected to exploit new applications in GPS, quantum radar, atomic clock, high-precision phase measurement and quantum imaging, etc. For example, PAN Jianwei and his team successfully created a 10-bit entangled state and observed photon phase super-resolution that broke the standard quantum limits[30]. A joint team from USTC (led by GUO Guangcan) and Israel developed new quantum weak measurement technology, and realized quantum high precision measurement with white light source; the precision of time measurement achieved attosecond magnitude and the measurement precision of corresponding distance is up to 0.1 nm, i.e. the movement of an atom-sized position can be identified. Meanwhile, the detector is simple and practical with stable performance and will not be influenced by environmental decoherence, which lays an important foundation for the quantum precision measurement technology to become practical[31].

Traditional information technology is increasingly approaching its physical limits. Quantum information technology will break through the bottleneck of Moore's law and provide unprecedented and powerful computing capacity and incomparable security. It will lead the next generation of information technology. At present, China has many world-leading achievements in quantum communication, and is keeping up with the best countries in quantum computing and quantum cryptography. With a position in this emerging field, China is trying to seize the strategic commanding height in future international competition.

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Artificial Life — A Promising Future of Synthetic Biology

1. *Synthetic Biology*: A novel multidisciplinary academic field that creates *Artificial Life*

On May 20th, 2010, in a *Science* paper, a self-replicating *Mycoplasma* controlled by a man-made genome, synthesized organically and assembled by a series of "synthetic biology enabling techniques", was claimed to be created by American scientists[1], which immediately made the news headlines over the world for the creation of the world's first synthetic organism, i.e., "*Artificial Life*". The success of constructing a completely man-made genome fully functional in bacterial cell also marked the discipline of Synthetic Biology, which was emerged at the dawn of the century, formally stepped onto the academic stage.

Significant progresses in genomics, systems biology, computational biology and quantitative biology developed in the past two decades, have provided an unprecedented knowledge base, which brings a revolutionary opportunity in designing "artificial" living systems/organisms for either comprehensive understanding of biological problems or creative constructing cell factories and molecular machines for practical purposes. Meanwhile, with the rapid development of high-throughput technology for efficient, high quality and low cost oligonucleotide synthesis and standardized construction of "plug-in" biological parts/devices and long-length DNA, circuits programming and genome synthesis are becoming so robust that eventually may evolve into a common routine practice of engineering.

In summary, *Synthetic Biology* is a novel discipline of *Life Science*, which integrates the knowledge of chemistry/biochemistry, physics/biophysics, and information science/bioinformatics along with the study of *Systems Biology* and based on the modulation concept and systematic design theory of *Engineering*, i.e., a bottom-up strategy for the goal of *synthesizing artificial life*. Biologically active molecules and genetic circuits, functional metabolic and/or physiological pathways or cellular organelles are to be artificially designed and constructed, resulting in de novo synthesis (or global modification) of cells, tissues, organs, individual organisms or even niches of ecosystems. These concept, knowledge and capability (enabling technology) have opened up a new opportunity for both studies tackling the long-time standing puzzles in life science such as the origin of life, the evolution of life and the structure-function relationship of biological molecules or systems and upgrading biotechnology and metabolic engineering into the era of engineering-based industry.

2. Recent progress in *Synthetic Biology*: Emerging of cutting-edge breakthroughs

Currently, the study of artificial life is undergoing a process of transition from simulation of natural conditions, modification or partial replacement of natural biological components with artificial devices to quantitative and computational biology based de novo design, synthesis, and assembly of complex life systems. The objects of artificial life studies and constructions are also extending from prokaryotes to eukaryotes, such as yeast[2]. In addition, the purpose of the research is shifting from proof-of-concept and the development of enabling technologies for the emerging Synthetic Biology, to mechanistic verification of the activities of complex life systems and the establishment of engineered systems such as genetic circuits and chassis. Synthetic genetic polymers, XNA, that never existed in nature creates a new opportunity for the study on the origin of life[3]. The rapid developed technologies in quantitative and computational biology have been able to successfully set up the genotype-phenotype prediction model based on bacterial physiology and genetics[4]. Synthetic genetic simulation circuit to achieve precise calculation function in living cells has built complex gene logical networks in mammalian cells[5]. The construction of biological transistors made by DNA and RNA is an essential step for "computing in living cells"[6]. The new technologies which can make simple and precise genome editing in eukaryotic cells/systems have been developed[7], which will certainly enable much easier modulation of transcription factors/elements and genetic circuits construction in eukaryotes[8].

Synthetic Biology has been heavily funded in developed countries and is under spotlight in the USA, European Union and UK, etc. The National Science Foundation (NSF) of USA initiated to fund the establishment of Synthetic Biology Engineering Research Center (SynBERC) back in 2006. Since then, a number of synthetic biology-related research projects have been successively funded by the United States National Academy of Sciences, the Defense Advanced Research Projects Agency, and the NSF. The European Commission FP7 have been funding four synthetic biology-related research projects, including cell factories and their applications, synthetic biology-related standards and safety research, etc. under the topic of "Biotechnology Emerging Trends" since 2010. In 2012, the Ministry of Business, Innovation and Skills of UK released a report of "Synthetic Biology Roadmap", which was followed by an immediate investment of more than 60 million pounds to support synthetic biology research to assure the global leadership of UK in this field.

3. Social and economic promises of *Synthetic Biology*: A revolutionary driving force in upgrading biotechnology

The accomplishment in synthetic biology for artificial life, its concept, theory and knowledge, and its enabling technology breakthrough and platform building, not only has provided us a new strategy for comprehensive understanding to the nature of life, but also has inspired a new wave of technology exploration worldwide, ever since its emergence. Because of the improvement in engineering and technical efficiency, there will be a fundamental revolution in the traditional pharmaceutical industry, chemical and biological manufacturing, hence enhancing productivity and changing human life. The establishment of the "efficient, clean, conservation, and sustainable" development mode will generate a profound impact on the future economic society.

The production of the antimalarial drug precursor artemisinic acid via the strategy of *Synthetic Biology* provides the most significant example. It was firstly realized in 2006 by constructing an engineered mevalonate pathway with amorphadiene synthase and a novel cytochrome P450 monooxygenase (CYP71AV1) from Arabidopsis annua in *Saccharomyces cerevisiae* (baker's yeast)[9]. Later, by constructing the complete biosynthetic pathway, including the discovery of a plant dehydrogenase and a second cytochrome that provide an efficient biosynthetic route to artemisinic acid, a high-yielding semi-synthetic production of artemisinin was achieved in 2013[10] and the corresponding large-scale production was launched.

4. *Synthetic Biology* in China: Achievements and problems, opportunities and challenges

Both the scientific communities (including research institutions) and the governmental funding agencies in China have been paying great attention to synthetic biology and artificial life ever since its emergence. As early as in 2008, the Chinese Academy of Sciences (CAS) already included "Artificial Life and the Origin and Evolution of Life" as one of the interdisciplinary cutting-edge scientific topics in the "Innovation 2050 Roadmap" program and promptly established the key laboratory of Synthetic Biology in its Shanghai Institutes for Biological Sciences. The Ministry of Science and Technology of China has deployed a series of synthetic biology-related projects in the "973" and "863" programs since 2010, including "Artificial synthetic cell factories", "Construction and assembly of artificial biological devices", "Artificial synthetic system for innovation and optimized synthesis of microbial drug", "Constructing new synthetic pathways for bio-materials employing synthetic biology strategy", "Stress resistance parts: Construction and related mechanistic studies", "Adaptation studies for artificial synthesized microbial systems", and the international cooperation program of "Synthetic Yeast".

Recently, Chinese scientists have made a great progress in synthetic biology fundamental research and technological innovation. With respect to basic research, a re-encoded *E. coli* chemotaxis system was constructed as a novel model for illustrating the principle of biological pattern formation[11]. A bioorthogonal redox system was devised[12], which may be further developed as a general and unique strategy to control synthetic pathways. For the purpose of synthesizing natural products *via* genetic engineered microorganisms, important breakthrough in terpenoides production should be mentioned. Employing genes encoding diterpene biosynthetic enzymes from the Chinese medicinal plant *Salvia miltiorrhiza*, a yeast chassis was engineered to produce miltiradiene[13]. This was further transformed into the oxidized product ferruginol (rust alcohol) upon introduction of the plant CYP450 enzyme CYP76AH1[14]. With a similar strategy, chassis yeast equipped with engineered pathway for protopanaxadiol biosynthesis was used for efficient screen of glycosyltransferases parts from *Panax ginseng* for one-pot synthesis of special ginsenoides, of which, the rare ginsenoid compound K for arthritis treatment was successfully produced and its biosynthetic pathway in ginseng plants was inferred[15]. For important bulk chemical production, technology breakthrough in high efficient and high yield succinic acid biosynthesis in *E. coli* via designed pathway, optimized parts/modules[16, 17, 18] and global regulation should be highlighted. In addition, the optimization of complex biosynthetic pathway in an efficient *in vitro* reaction system[19] and the achievement of direct bio-transformation of light energy to ketone production by establishing a new metabolic pathway in cyanobacteria[20] are both intuitive. In the direction of application in agriculture, a female-specific synthetic lethal gene circuit in silkworm was constructed to facilitate high yield and high quality silk production *via* solely cultivating male silkworms[21]. Although, after more than five years of hard work, we have built up the foundation, both in human talents and institutional logistics, for synthetic biology in China; as a whole, we need to be more innovative in scientific research and more translational in biotechnology R&D to catch up the fast development trends in the field and meet the urgent demand of our society.

Therefore, taking the advantages in both integration of interdisciplinary research subjects and organizing multidisciplinary research teams, innovative projects focusing on key scientific and technological challenges should be promptly initiated. A possible planning strategy is to take the key issues in the evolution of biological molecules and systems as the core scientific problem of research. Along with that direction, specific projects will be designed based on the breakthroughs in the field of artificial life research, including artificially designed and synthesized biological molecules, functional pathways, cellular organelles or eukaryotic chromosomes. A series of enabling technologies will be developed, particularly *via* the efforts of key laboratories and engineering technology platforms. Meanwhile, starting with the innovation of certain important "products" related to national welfare and people's livelihood such as medicine, agriculture, find chemicals, biomaterials, green energy, environment protection and remediation *etc*., artificial biological systems with large-scale application potential will be explored. The transformation of "synbio-manufacturing" from basic research to industrialization will be facilitated, which may eventually support the establishment and development of a sustainable socio-economic system in China.

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Human Brain Neural Connection Diagram is Expected to be Mapped

Human brain is one of the most complicated systems existing in nature. It is estimated that approximately 10^{11} neurons structure a highly complicated network in an adult brain through interconnection via 10^{15} synapses, thus research breakthroughs in visualization of the whole brain neural networks with the resolution level of individual neurons could serve as the base for understanding of brain functions and diseases. The Human Connectome is a study designed to run comprehensive analysis, as well as simulation of the neural connections and network structures of brain functions so as to unravel the secrets of how human brains work. The project seeks to, on all levels varying from macro view (encephalic region) to micro angle (individual neurons), present a thorough depiction of the frame network of human brains from overall to individual level. It's a comprehensive study of human brain structure and mode of functional connectivity. The study shall generate significance in terms of helping us understand the working mechanism of human brains as well as the mechanisms of development, onset and progress of brain diseases, and also help drive the study of artificial intelligence system forward.

1. Current status of international development

Drawing human brain neural connection diagram has become the high ground in life sciences research and its future development around the world. In 2004, the US NIH proposed the framework for "NIH Blueprint for Neuroscience Research" and set up the "Human Connectome Project" (HCP) with the purpose of studying neural connections in different brain regions on millimeter level and drawing diagrams of different living brain structures and functions. The "Brain Activity Map" (BAM) proposed by Obama, the President of the United States in February 2013, on the other hand, aims at making diagrams for "every electrical pulse on every single neural cell" in living human brain. In April of that same year, the United States officially launched a 10-year project called "Brain Research through Advancing Innovative Neurotechnologies" (BRAIN). In early 2013, the European Union also decided to invest one billion Euros in the 10-year "Human Brain Project" with the purpose of building a complete brain using computer simulation. Relevant research plans have been deployed by other countries including Japan, the UK, Germany, etc.

Development and innovation of various technologies, such as image technology, optogenetics, nanotechnology, invasive advanced materials, neuroscience biobank and remote monitoring technology, have been a boost to the rapid development of the Human Connectome Project. Diffusion tensor imaging (DTI) and magnetic resonance imaging (MRI) are the main imaging tools used in studying human brain structure and functional connection at present; optogenetic technology could help us run further analysis on how neurons interact with one another to constitute functions by regulating brain circuits with light; and analytic network algorithms serve as an important tool for studying topology of macro-scale brain network.

Studies of Human Connectome have embraced rapid development, and was rated one of the six noteworthy scientific fields of 2013 by *Science*. In the first half of 2013, HCP published its first two sets of research data and drew a three-dimensional connection diagram of human thinking for the first time, which altogether constituted a total data volume of 4 TB[1,2]. Later in June, the very first ultra-high resolution three-dimensional connection diagram – "Big Brain" was successfully drawn. It was clear enough to show the cell structure of cortex, even the micro current between cerebral neurons and was able to serve as a reference map for medical science and drug development[3]. In August 2013, researchers were able to successfully simulate 1 second of network activity of human brain nerves using super computer. Now, German researchers are trying to present neuromorph system on silicon chips by infusing neurons into the chips, which will lay the foundation for construction of brain computer model.

2. Current status in China

China has always been highly supportive in the field of brain sciences. Its "National Outline for Medium and Long Term S&T Development" (2006–2020), "National S&T Development Plan during *the 12th Five-Year Plan* Period", "Biotechnology Development Plan during *the 12th Five-Year Plan* Period" and "Development Plan of Natural Science Foundation of China during the *12th Five-Year Plan* Period" have all made arrangements for research in brain sciences. In 2010, the Ministry of Science and Technology launched the "Brain Network Studies of Imaging and Its clinical Application", one of the many projects in the "973" Program. The National Natural Science Foundation of China launched a major research project called "Neural Circuit Base of Emotions and Memories" in 2011, providing concrete support for research in brain network representations of cognitive function and impairment of two kinds, "Emotion" and "Memory", as well as its relevant technologies. In 2012, the Chinese Academy of Sciences launched Strategic Priority Research Project (Category B) of the "Interface Chart of Brain Functions" in the interest of describing the functional connection and operation between nerve cell clusters of special category in different brain regions. It also seeks to thoroughly describe, based on the development state of brain sciences and latest technologies, the construction and operating mechanism of the neural network connections undertaking important functions of a few selected important brain functions (perception, emotion, learning memory, decision making) under normal physiological and pathological states, in the hope of combining the results obtained to draw a complete brain activity diagram.

With the support of relevant policies, multiple institutions including the Chinese Academy of Sciences, Beijing Normal University and Tsinghua University have all launched research programs in brain sciences and achieved a number of results. In 2007, researchers from Beijing Normal University created the first sketch of living brain structure connection network and discovered that the thickness of grey matter in different brain regions is characterized with "Small-World" organization[4]. They also found that Amnesic Mild Cognitive Impairment and Remitted Geriatric Depression shared similar neural circuit damage mode, which provided new ideas for studying of the pathogenesis of Alzheimer's Disease; Beijing Normal University and NIH of the United States worked together to reveal that there was close tie between blood supply and brain function topology[6]. Researchers from Chinese Academy of Sciences formally introduced the concept of "Brainnetome"[7]. In aspect of technology, the research fellows from East China University of Science and Technology developed a brand new photoactivation operating system called the LightOn System[8]; the Dual Color Calcium Imaging recently developed by researchers from the Chinese Academy of Sciences can be used to obtain dynamic information on electrical activities of nerve cells, and it will give an extra boost to the preparation of Human "Intelligence Blueprint". Huazhong University of Science and Technology began to develop high resolution whole brain neuron network visualization instrument, with the purpose of producing "Brain Remote Sensing Satellite" that could reveal the secrets of human brains[9]. In the meantime, scientists from research institutes such as the Chinese Academy of Sciences have provided standardized base for future association studies of brain functional connectome based upon large database[10].

Worldwide heavy investment and rapid development of technologies are driving brain sciences into a new era. Human Brain Neural Connection Diagram which is comparable of Human Genome Project is expected to be mapped, and it will bring great scientific, social and economic rewards.

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Revolutionary Breakthroughs in Photosynthesis and "Artificial Chloroplast"

As the largest-scale reaction process of energy and matter transformation as well as the largest-scale solar energy utilization on earth, photosynthesis provides organic compounds, energy and oxygen for almost all life activities. Therefore, the process of photosynthesis can be considered to be closely related to the solutions for such issues as food, energy, resource crisis and environmental changes. The molecular mechanisms of high-efficiency energy absorption, transfer and conversion in photosynthesis constitute the core issues of photosynthesis research and are on the cutting edge of science. The illustration of the photosynthetic mechanisms will exert significant impact both scientifically and practically. Numerous researches have revealed that the light energy utilization efficiency of plants is far from reaching the theoretical limit, showing huge potential in tapping and improving the utilization efficiency. At present, the focuses of photosynthesis researches are as follows: (i)molecular mechanisms of high-efficiency light energy conversion and the regulation principles, (ii)exploring the key genetic resources that regulate photosynthetic efficiency from the perspective of heredity, (iii)fostering crop and energy plant varieties with high photosynthetic efficiency as well as the realization of artificial simulation systems of photosynthesis, (iv)developing new technologies capable of fixing solar energy efficiently and converting the energy into clean ones[1].

1. Photosynthesis researches boost rapid development of agriculture and energy industries

Organic compounds synthesized by plant photosynthesis on the earth amount to 220 billion tons each year, equivalent to 10 times as much as the energy consumed annually by human. Furthermore, photosynthesis is the material basis for crop yield, and 90% to 95% of a plant's dry weight is derived from it. As a result, improving efficiencies of crops' light energy conversion and carbon assimilation is an important way to improve crop yield.

The success in revealing light energy transfer and conversion mechanism of photosynthesis as well as in analysis of the spatial structures of photosynthetic membrane protein complexes may make the photosynthetic membrane system become the first complicated biological membrane system that can be explained with physical and chemical concepts at the atomic level. These can not only reveal the mysteries in the high-efficiency energy conversion of photosynthesis, bridge the seemingly impassable gap between the physical world and life world, facilitate the theoretical researches on complex system condensed matter physics and chemistry, enrich and develop electron transfer as well as energy transfer theories of super-molecule system, but also lay a theoretical foundation for improving the crops' light energy conversion efficiency, opening new paths to solar energy utilization, as well as researching and developing biological electronic devices and biological chips, and producing clean, re-usable energies on a large scale based on the principle of bioconversion of solar energy[1].

Based on the knowledge of natural photosynthesis process, it has become a key topic in the field of energy research that high-efficiency water splitting and CO_2 reduction can be achieved by developing artificial photosynthesis with bionic technology to produce solar fuel from solar energy. Centering on the molecular mechanisms of high-efficiency energy conversion and the regulation principles, current researches mainly explore the major science and technology problems such as new thoughts, methods, technologies, and materials encountered in the process of mimicking photosynthesis, developing solar bio-fuel cells, technologies to produce hydrogen from algae and photosynthetic micro-organisms and oil production technologies. These research outcomes will promote the formation of the emerging industries which utilize biological conversion of solar energy, and thus exert profound impact on the world energy and resource structures.

2. Creation of artificial photosynthesis system attracts increasing attention

The great challenge for mankind to meet the needs of energy system for sustainable development is to provide the energy needed while reducing CO_2 emission and keeping the eco-environment security. Therefore, an energy system on the basis of sustainable development must be sought and established. Establishing natural and artificial solar energy conversion system based on photosynthesis principle to produce clean energy is an important path to solve the current energy and environmental issues.

How to fix solar energy and efficiently and convert it into the clean energies is one of the important scientific and technical issues nowadays. As an important approach to solve the above issues as well as a significant direction of future energy strategy, mimicking photosynthesis has drawn much attention of governments and scientists of every country. For example, EU has launched "Artificial Leaf" Program to conduct researches on the photovoltaic technology, mimicking photosynthesis, modification of photosynthetic carbon fixation approach, *etc*.; the US has launched the research program of "Mimicking Photosynthesis for Producing Hydrogen from Solar Energy"; the UK Biotechnology and Biological Sciences Research Council (BBSRC) and US National Science Foundation (NSF) have invested € 6.11 million in exploration of approaches to break the barriers to photosynthesis, so as to greatly boost the yields of crops and bio-energy crops[2].

It has always been the research emphasis to break the bottlenecks such as molecular mechanisms and the regulation principles of light energy absorption, transfer and conversion during photosynthesis and to improve the efficiency of crop photosynthesis. For example, Okayama University in Japan is the first to analyze the spatial structure of photosystem II photosynthetic membrane water splitting protein at a resolution of 1.9 Å[3]. This structure was selected by the journal *Science* as one of the Top 10 scientific breakthroughs in 2011, and was considered as "not only essential for life; but also may hold the key to a source of clean energy"[4]. The latest research outcomes of Rensselaer Polytechnic Institute provided important information about photosystem II, addressing critical issues on solar water splitting reaction in photosystem II[5]. Researchers from the Department of Chemistry of the Royal Institute of Technology in Sweden successfully developed a molecular catalyst capable of rapidly oxidizing water into oxygen, for the first time, which makes artificial water-splitting comparable to that of the natural photosynthesis rate[6].

In recent years, significant progress has been made in the research field of establishing "artificial chloroplast" by mimicking plant photosynthesis system. MIT scientists replicated in laboratory the photosynthesis process during which water is split into hydrogen and oxygen, enabling artificial production of hydrogen and oxygen possible[7]. With the approach of synthetic biology, researchers from University of Glasgow tried to create a kind of artificial "leaf" capable of converting solar energy into liquid fuel to duplicate the chemical reaction similar to that of natural photosynthesis[8]. Scientists of University of East Anglia are trying to artificially simulate photosynthesis process by putting micro solar panels into microorganisms[9].

Additionally, with the approach of synthetic biology, researchers have also designed assembly of various photosynthetic biosystems. Researchers from University of Tennessee produced energy by controlling cyanobacterial photosystem I[10]. Researches conducted by University of Copenhagen in Denmark have broken up the compartmentalization of plant cell functions and transferred the whole metabolic pathways for production of natural bioactive compounds in endoplasmic reticulums into chloroplasts, which opened a new pathway for synthesizing massive natural chemical substances in chloroplasts[11].

3. China plays an important role in basic researches and application development of photosynthesis

China plays an important role in photosynthesis researches due to its significant theoretical and practical impact. In the last ten years, the Institute of Botany, the Chinese Academy of Sciences (CAS), sponsored an interdisciplinary two-phase "973" Program involving biology, physics, chemistry and agriculture, which focuses on the research of photosynthesis mechanism. The Institute of Biophysics, CAS, coordinated the Major Scientific Issues-driven "Photosynthesis and Artificial Leaf" Project of "973" Program. Thanks to the constant research efforts of CAS in the fields such as photosynthesis mechanisms and interdisciplinary bionic simulation programs, China has made achievements of great international importance in the photosynthesis field, and made astounding breakthroughs in the structure and functions of photosynthetic membrane protein, especially in the major issues such as the researches on the structures and functions of photosystem II as well as the self-assembling and regulation mechanisms of photosynthetic membrane protein[12,13]. As to bionic simulation, Chinese scientists successfully assembled the bio-organic solar cells based on light-harvesting complex II (LHCII) for the first time, which not only expands the absorption spectrum of organic cells, but also improves light energy utilization to a level of 30%[14]. With the ongoing significant international influence of China's photosynthesis research achievements, *the 15th International Congress on Photosynthesis* was successfully held in China for the first time, which was organized by Institute of Botany, CAS in 2011[15].

Future photosynthesis researches will foster plant breeds with high photosynthetic efficiency to substantially increase crop yields with the combination of the new generation of transgenic technology and molecular mechanism design. By crossing and integration bionics and synthetic biology researches, novel bio-nano-material devices and biocatalysis molecular devices can be designed and manufactured to efficiently convert solar energy into chemical energy and realize massive hydrogen production from "artificial photosynthetic cells" and various catalysts, leading to revolutionary advances in the bio-utilization of the virtually un-limited solar energy.

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Information Service Entering the Era of Computing for the Masses, Driven by Human-cyber-physical Ternary Integration

1. Human-cyber-physical ternary computing — a paradigm shift to computing for the masses

Over the past five decades, the development of information technology (IT) has mainly focused on high-performance, general purpose and large-scale production, while affordability, usability, reliability, security and customization have not received enough attention. Future information products and services should meet the personalized demand of billions of individual users[1]. This trend is called Computing for the masses (or e-People).

Traditional computing is dominated by institutional computing in the cyberspace, providing IT value (IT hardware, software, and services) to companies (e-Business), research institutions (e-Science), and government agencies (e-Government). Computing for the masses is different in two aspects: it provides business value to the billions of individual users in their work and lives, and it extends computing processes beyond the cyberspace boundary. Future computing processes will move from the unary cyberspace into the human-cyber-physical ternary universe, utilizing the resources of the human society (human), the cyberspace (cyber) and the physical world (physical), and executing personalized big data computing[2]. Computer science and computing industry will see a paradigm shift into a paradigm of human-cyber-physical ternary computing.

A typical human-cyber-physical ternary universe is an open environment consisting of humans, an embedded system (the cyber component) and physical environment. The embedded system can enhance the interaction between humans and the physical environment. The human-cyber-physical ternary universe can infer user's intention by measuring human cognitive activity through body and brain sensors. The embedded system can then transform the user's intention into robot control signals and make robotic actuators represent humans to interact with the physical environment. Finally, decisions can be made and close the loop by humans' observation of the physical world interactions[3].

2. Prominent features of information service entering the era of computing for the masses

In the coming decade, human-cyber-physical ternary integration will make information science penetrate into many areas of economy and social services. The intelligence level of work and life will be improved via the open human-cyber-physical collaboration and interaction. Traditional computer science will evolve into a new information science featuring human-cyber-physical ternary computing. Traditional information technology will be upgraded to sea-network-cloud information network technology, with new hardware, software, application modes, protocols and standards[4].

Computing for the masses exhibits the following four specific features: (1) value-augmenting mass adoption: by 2050, China's IT users should cover over 80% of the population, with the per capita IT expenditure increasing more than 13 times; (2) affordable computing: each mass user's total cost of IT usage should decrease significantly while acquiring equal or higher IT value; (3) sustainable computing: IT capability should see orders of magnitude growth but energy consumption and emissions should not; (4) ternary computing: the above three features can only be achieved with transformative innovations. A major source of opportunities for such innovations is from the coupling and interaction of the human society, the cyberspace, and the physical world[5].

3. Economic-social effects of information service entering the era of computing for the masses

Human-cyber-physical ternary universe is a dynamic open network society composed of multiple humans, multiple computers, and multiple physical objects. Under the effect of human-cyber-physical ternary integration, cloud-driven e-People with humans as the starting point and individual computing demand as the first load will exceed e-Business, e-Science and e-Government and become the main service mode, which will provide the masses with high-quality services in the aspects of health care, geographic information, e-business, research and education, entertainment, and so on. For example, many exciting applications will emerge in the fields of human-computer interfaces, control-aided robots, intelligent artificial limbs, interaction repair or enhancement between humans and physical world, etc. Meanwhile researchers can address the challenges in crossing fields such as semi-automatic robots, wireless body area network, embedded system design and development of intention inference algorithms in a better way[6]. It is estimated that the computer market in China will reach RMB 1,000 billion per year during 2040–2050, driven by computing for the masses[7].

4. Extensive attention of the industry on relevant researches

Currently, researches on human-cyber-physical ternary integration and computing for the masses have aroused extensive attentions in different industries. The trend towards human-cyber-physical ternary universe is recognized in the strategic study reports on information technology development for the period of 2011 to 2020, by both the Ministry of Science and Technology of China and National Natural Science Foundation of China. The concept of human-cyber-physical ternary computing (and the computational lens and computational thinking proposed by American scientists) stimulates the formation of new cross-disciplinary subfields and communities. In China, research on Internet of Things has attracted a lot of attention and has become a degree program in a few dozen universities. Research on evolution computing is conducted in Harvard University. Also, some new academic institutions have been established, including the Institute of Computational Thinking in Carnegie Mellon University, and the Institute of Computational Sustainability at Cornell University[8]. Other strategic planning and research projects related to human-cyber-physical ternary integration include the Internet of Things Strategic Research Roadmap proposed by European Commission[9], the Human Brain Project of future emerging technology flagship programs of European Commission[10], Strategic R&D Opportunities for 21st Century Cyber-Physical Systems published by National Institute of Standards and Technology (NIST)[11] and the Industrial Internet proposed by General Electric[12], etc.

5. Relevant R&D progress actively propelled in China

In recent years, relevant Chinese authorities and the Chinese Academy of Sciences (CAS) have funded research projects on human-cyber-physical ternary integration and computing for the masses and remarkable research progress has been achieved, indicating China has laid a favorable foundation in this direction.

The concept of ternary computing for the masses was originally proposed in 2001, when China started to make her 2001 to 2020 mid-term plan of science and technology development. The concept was further developed in the subsequent years in a number of studies by CAS[8]. In 2007, the CAS sponsored a two-year study on the challenges, requirements and potential roadmaps for information technology advances into year 2050. The researchers of the CAS presented a perspective on a key finding of this study: a new paradigm, computing for the masses, is needed to cope with the challenges facing IT in the coming decades[5]. In 2009, the CAS published the *Information Science and Technology in China: A Roadmap to 2050*, in which it is pointed out that developing ubiquitous information network is an important demand for economic and social development and scientific research of China and the thought of human-cyber-physical ternary universe and popularized information technology benefiting the masses are proposed[7, 13]. In 2012, the CAS launched a strategic priority research program titled "New Generation of Information Technology Research for Sensing China", and human-cyber-physical ternary integration was one of the key ideas[14]. In recent future, in order to further enhance the value of computing technology, reverse the stagnation of traditional computing industry development and achieve the development objectives of information service for the masses, the information service industry will inevitably take great strides forward towards the age of computing for the masses under the trend of human-cyber-physical ternary integration.

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Power Grids' Operation Mode to See Changes from AC to DC or AC/DC Hybrid

1. Development of renewable energies brings challenges to the power grid technologies

With the development of power generation technologies for renewable energies, the pattern of clean energy system, in which the renewable energies play the principal role and the electrical power is the main terminal energy, will take shape gradually. In 2012, for example, the global installed capacity with the renewable energies exceeded 1,470 GW (out of which 480 GW was non-hydro renewable energies), achieved a year-on-year increase of 8.5%, accounting for more than 26% of the total global installed capacity, and supplying 21.7% of the electrical power in the globe. The installed capacity of power generation with the solar energy first toppped the 100 GW mark, and the solar energy became the third key renewable energy, just next to hydropower and wind power[1].

Power generation with the renewable energies features intermittence, volatility and dispersion. The increasing connection of centralized renewable energy power plants and distributed renewable energy power have posed great challenges to the future development of power grids.

2. Evolution and features of power transmission technologies

In 1882, the first power transmission line was established in the world. It was a DC one. Unfortunately, the early DC power transmission featured big loss of power and difficulties in power transformation, and was soon replaced by AC power transmission. However, as the long-distance power transmission line increases and the wide-area power grid appears, AC power transmission has faced some technical bottlenecks, such as poor system synchronization and stability, and low power transmission efficiency. Meanwhile, the operational security of AC power grids becomes increasingly prominent.

At the same time, DC power transmission technologies are continuously advancing as the development of high voltage converter technologies and high power electronic devices. Since the 1950s, the high voltage DC (HVDC) power transmission technology has stood out conspicuously. It converts the AC power of the sending terminal into DC power at the converter station, and sends the DC power through the DC line to the inverter station, where the DC power is inverted into AC power, which is sent to the AC system at the receiving terminal. The benefits of this technology are as follows: (1) the overhead line of HVDC power transmission system needs positive and negative leads only, allowing for high power, low loss and long distance power transmission; (2) it enables the parallel power transmission of AC and DC power, and non-synchronous networking, effectively restricts the power oscillation of AC line by adjusting active power, and provides transient and dynamic stability of AC power; (3) by changing the operating mode of the sending and receiving terminals, it controls the size and direction of system flow, thus eliminating or avoiding the large amount of pass-through flow; (4) for long distance power transmission, the DC power grid features low investment, easy expansion, and great benefits.

3. Development of the HVDC power transmission technologies in the world

Over 100 HVDC power transmission projects have been established or currently under construction[2], and the researches on multi-terminal DC power transmission and DC power grid technology are increasingly going deep. Great breakthroughs concerning HVDC power transmission technology have appeared one after another.

In 1997, ABB developed the voltage source converter with the high power insulated gate bipolar transistor (IGBT) for the first time, successfully achieving turn-off component conversion. This DC power transmission technology enables separated reactive/active power control, eliminates the need for filtering and reactive compensation devices, provides the ability to empower the inactive loads, and doesn't change the polarities when the flow converting, so it is more suitable for establishing the multi-terminal DC power transmission line and DC power grid. In 2010, Siemens also successfully developed the new modular multi-stage IGBT converter, combining hundreds of microscopic converters into one appliance to achieve the capacity of over 1,000 MW. Another bottleneck for DC power grid is DC circuit breaker. In 2012, ABB announced their breakthrough in this regard, a 320 kV prototype, which lays a solid foundation for DC power grid construction.

In recent years, the power grid modernization has been taken as a key part of the strategic plan and R&D schedule in some developed countries. In 2005, EU set up the platform for intelligent power grid technologies, and henceforth launched the *European Power Grid Vision and Strategy for the Future* (2006)[3], *European Agenda for Strategic Research on Power Grid in the Future* (2007)[4], *European Plan for Strategic Deployment of Power Grids in the Future* (2010)[5], and *Agenda for Strategic Research on Intelligent Power Grid up to 2035* (2012)[6]. In the future-oriented power grid design of Europe, the concept of Super Grid is initiated, aiming to consolidate the distributed national markets into a European common power market through construction of high density HVDC power grids, and attempting to build a large-scale solar power generation base in the desert of North Africa, for the purpose of supplying power to Europe via HVDC lines.

As the leader in HVDC power grid technologies, Germany released its *2020 Roadmap for Energy Policies* in 2009, according to which six billion euros will be invested in intelligent upgrading and reconstruction of the 60,000 km national power grid before 2015[7], and the current nuclear power stations will be all decommissioned in 2022. Germany plans to set up four HVDC lines for the national power grid, transmitting power from its northern areas where there are rich wind power resources to southern areas.

In 2003, the US Department of Energy formulated the *Grid2030*[8] and *the National Roadmap for Power Transmission Technology*[9], proposing to leverage the backbone power grid architecture that incorporates the superconducting technology, energy storage technology and DC power transmission technology, to build the American power grid into a comprehensive one that consists of the nationwide backbone grid, regional power grids, local power distribution grids and distributed microscopic power grids.

It can be predicted that, as the renewable energies increasingly connected into the power grid, the future power grid will shift from AC to DC. HVDC power transmission technologies will also change the power supply mode in the relevant areas where the data communications require the higher power density, reliability and stability, thus substantially affecting the energy production, transmission, distribution and utilization, as well as the structure of power industry. A number of hi-tech industries are expected to emerge.

4. Great demand of China to develop HVDC power grid technologies

Up to the end of 2011, the installed capacity of grid-connected power generation with the renewable energies was up to 51,590 MW, accounting for 4.89% of the total installed capacity; and the grid-connected generating capacity with the renewable energies was 93.355 billion kwh, accounting for approximate 2% of the total generating capacity. Wind power played a major role. The grid-connected wind power approximately accounted for 87.33% of the grid-connected installed capacity with the renewable energies; and the wind power generating capacity accounted for 78.38% of the grid-connected power generating capacity with the renewable energies.

From a long term perspective, China's power generation with renewable energies will develop massively on the basis of the available resources, and the renewable energies will play a major or even dominant role in the future. According to statistics, the amount of solar radiation on land nationwide is equal to 2,400 billion tons of standard coal; the amount of wind energy resource 10m above the ground is approximately 3.226 billion kw, and the wind energy reserves that can be exploited amount to approximate one billion kw; the theoretical reserves of China's hydropower resources amount up to 700 million kw, accounting for 40% of our total conventional energies.

As the construction acceleration and scale expanding of our renewable energy basis, it is hard for the existing AC power grids to adapt the development trends. And there are more and more difficulties for the traditional power equipment, grid structure and operating technologies to cater to the super-large scale renewable energies. This is a great challenge to the dynamic security and stability of power grids. For this reason, new technologies, new equipment and new grid structures must be introduced to address the in-depth changes of energy patterns in the future.

5. Current developmental situation of China's DC power transmission technologies

China's HVDC power grid technologies started very early. In August 1990, the Gezhouba–Shanghai Nanqiao ±500 kV DC power transmission project was completed. This was China's first large DC power transmission project of 1,054 km, with a nominal transmission capacity of 1,200 MW. After that, China consecutively finished the Sanxia–Changzhou, Sanxia–Shanghai and Sanxia–Guangdong ±500 kV DC power transmission projects, totaling over 2,900 km.

In recent years, China has started to accelerate the construction of ultra-high voltage DC power transmission projects as guided by the spirit of "building the solid AC and DC interconnected grid architecture". In July 2010, the demonstrative Xiangjiaba–Shanghai ultra-high voltage DC power transmission project was finished and already put into operation; currently, the Jinping–Sunan, Hami–Zhengzhou, Xiluodu–Jinhua and some other ultra-high voltage DC power transmission projects are underway. According to the state grid plan, it is also proposed to establish the North China–East China–Central China 1,000 kV AC grid framework, which will be asynchronously connected with the West China and Northeast China grids via DC; the power needed from outside is input through ultra-high DC and ultra-high AC. Shanxi, West Inner Mongolia, North Shaanxi, Ningxia, Xilinguole League and other large coal/wind power grids, Sichuan hydropower grid and coastal nuclear power grid are connected with it through ultra-high AC, while the large coal/wind power grids in Northwest China and Northeast China as well as the large hydropower grids in Southwest China are connected with it through ultra-high DC transmission channels[10].

According to the *12th Five-year Plan for National Energy Technology Development*, the main FACTS facilities will be homemade; the fault current limiter, DC circuit breaker, electronic power transformer, superconductive energy storage system, superconductive DC power transmission and other demonstrative systems will be developed; and VSC-HVDC DC converter will be applied in the 100 kV system.

It is estimated that China will make breakthroughs in basic DC grid theories and multi-terminal DC power transmission technologies, and establish the regional DC power grid in the northwestern areas where there are rich renewable energies and resources, for the purpose of massively applying renewable energies in certain areas and improving the proportion of renewable energies.

6. Outlook of the development of China's DC power grid technologies

It is a priority task to develop the DC power grid to resolve the issue that renewable energies will be massively connected to the power grid in China in the future. To make systematic breakthroughs in the theoretic system and critical technologies for the DC power grid, China still have to deal with a number of important technical issues, i.e., researching on the evolution of power grids and the structure of future DC power grids and establishing the security and stability theory of DC power grids; developing the new high-performance sensors and their network, DC power grid modeling and simulation technology, DC power grid cloud computing and sea computing technologies, and the construction of the common information platform and information security technologies for wide area DC grids; making breakthroughs in a number of key technologies, including the DC circuit breaker and limiter technology, and the technologies for wide area DC grid scheduling, optimized operation and control, failure positioning and network restructuring, distributed power grid and its connection and energy storage, and superconductive power; and developing new electronic power components, high voltage and high power electronic equipment, new electrical materials, etc. The Institute of Electrical Engineering, CAS has carried out the researches on the rationality and network architecture of China's future DC power grid construction, the complementary utilization of wide area renewable energies and resources, superconductive DC power transmission technologies and so forth, and has started the construction of demonstrative DC power grid system based on the complementation of multiple energies (including multiple energy storage systems). A demonstrative 360 m 10,000 A superconductive DC power transmission project has been completed, too.

It is predicted that before 2020, China will establish the theoretical system, technological system and standard system for DC power grids in line with China's national situations, and make all-round breakthroughs in critical DC power grid technologies, laying a solid foundation for the development of China's new generation power grid. The revolutionary transition of future power grid to DC mode will bring along a large number of opportunities for technology innovations and a variety of emerging strategic industries. The systematic breakthroughs in DC power grid technologies will technologically ensure the full establishment of China's future clean energy system.

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Solar Photovoltaic Grid Parity Will Come True

1. Current situation and challenges of solar photovoltaic

Solar photovoltaic (PV) is the most promising direction with the fastest growth among solar power technologies. The PV installed capacity has enjoyed an annual growth rate of 60% since 2008, and by 2012, the global accumulative installed capacity exceeded 100 GW for the first time[1]. It is predicted by the International Energy Agency that PV will generate about 11% of the world's electricity by 2050, reducing CO_2 emission by approximately 2.3 billion tons annually[2].

However, solar PV also faces significant challenges. Firstly, solar energy has low energy intensity and is susceptible to sunlight hours, radiation levels and other natural factors. Secondly, photovoltaic system cannot reach the efficiency of conventional energies due to its basic electricity-generating principle. Finally, because of factors such as materials and manufacturing, photovoltaic power has an inferior position in cost compared with conventional energies, making it difficult to compete with hydro-power, coal power and nuclear power in terms of price.

2. Key technological problems facing low-cost PV

Currently, PV is heavily dependent on government subsidies. To get rid of such dependency and to popularize market rule, the key for PV to become one of the primary alternative energies is to reduce the cost of electricity generation to a comparable level as conventional energies. The reduction of PV cost is usually proceeded in several ways: (1) cutting down the cost of large-scale industrial production; (2) improving the utilization efficiency of silicon, which is the main material of solar cell, and thus reducing the cost of materials; (3) vigorously developing new materials and new technologies to improve the conversion efficiency of solar power. The core of these approaches is to reduce production cost to the greatest extend by improving the conversion efficiency of solar cell, therefore to decline the overall cost of generating electricity and achieving grid parity. However, how to improve the absorptivity of sunlight and the generation rate of exciton excited by light wave, and how to effectively accelerate the transfer of photo-induced electron and holes are the key scientific problems. And the key technologies include studying new concepts and mechanisms of how to improve the conversion efficiency of solar cell, improving the performance of photovoltaic materials, optimizing the designing of photovoltaic device structure, and grasping preparation and characterization technology of photovoltaic materials and devices.

3. Prospects of solar photovoltaic

The gradually progressive technologies of PV industries and the expending global PV market, with the marked drop of raw materials price, have provided the foundation for PV to achieve grid parity. The cost of the first generation of solar cells, which were made of crystalline silicon, is very high. Today the maximum conversion efficiency of solar cells has reached 22% and it is being thinner and more efficient. At the same time, with the advance of technology and the expending of manufacturing, the cost of the first generation solar cells is declining dramatically while the price of crystalline silicon has dropped from $4 per watt (2006) to less than $1 per watt. The second generation, called semiconductor film solar cells, has a conversion efficiency of 12%. Industrialized generating efficiency is 8%–10%, the cost of which is still declining compared with the first generation. For example, the average price has dropped 20% in 2012[3], and it will continue to develop towards higher efficiency, stabilization and long-life. The third generation can reach an efficiency of 35% and is expected to make a breakthrough, making it possible for PV to compete with conventional energies in terms of price.

PV has become a common concern and a key emerging industry with strategic significance in world's major countries. Governments are increasing input to stimulate the development of PV. The U.S. is planning to have an accumulative installed capacity of 7GW and the total cost will be declined by 75% to about $1/W (6 cents/kWh) by 2020. At that time, large-scale photovoltaic system will be competitive compared with other energies even without subsidies, facilitating the widespread of solar power on a national scale[3]. As for the EU, it is expected that by 2020 PV will generate 12% of EU's power demand and the cost of traditional turnkey PV system will be reduced to less than €1.5/W. In sunnier South Europe, the cost will be 7–14 euro cents/kWh[4]. And it is shown in its PV roadmap that Japan holds the idea of "grid parity" and establishes a goal that by 2017 the cost of PV will be reduced to 14 yen/kWh and by 2025 it will be reduced to 7 yen/kWh, making solar PV to be one of the primary energies[5].

These years, the solar PV industry in China is booming and has become one of the few internationally competitive industries with the prospect of reaching the world-leading level. It has formed a unitary industrial system which includes silicon materials and silicon chips, PV cell and its modules, inverter and control equipments. In 2009, the Chinese Academy of Science launched a solar power action scheme, attaching a great importance to the breakthrough of new theories, new methods, new materials and new processes and setting a three-stage-goal: distributed utilization in 2015, substituted utilization in 2025 and scale utilization in 2035. In 2012, the China government established *the 12th Five-Year Plan of Solar Power Development* and *the 12th Five-Year Special Plan of Solar Power Technology Development* and on July 4th, 2013, it established *Several Opinions about Stimulating the Healthy Development of PV Industry by the State Council*[6], and planned to increase solar PV installed capacity to 35 GW and to reduce PV grid price to ¥1/kWh in 2015. At the same time, it was expected that the accumulative installed capacity in China will be 50 GW or even 100 GW and in this case, the price per kWh will be ¥0.6 to ¥0.8.

In conclusion, with the increase of PV efficiency and the reduction of generating cost, solar PV price is predicted to reach grid parity around 2020. This achievement will positively accelerate the utilization of renewable energy sources and will trigger a great reform in the energy structure.

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Deep Geothermal Energy to Become One of the Major Renewable Energies

1. Main science and technology connotation and significance

Geothermal energy includes that from shallow stratum and that from deep stratum. Shallow geothermal energy refers to the low-temperature heat contained in the soil, gravel, and groundwater within several hundred meters below the earth's surface[1]. Under current technological and economic conditions, this energy can be fully developed and utilized. Deep geothermal energy refers to the higher-temperature heat resources contained in the hot dry rocks at thousands of meters below the earth's surface. Enhanced geothermal system (EGS) as a mining technology targeted at hot dry rocks has become a focus of geothermal engineering research in recent years. In an EGS, water (or other working fluids like CO_2) is injected via the injection well to generate underground circulation within the rocks.

Along man-made fracture zones, water in contact with the rocks gets heated, and is pushed back to the surface via the production well. The system forms a closed circuit. EGS is a man-made geothermal system that builds a geothermal reservoir with engineering measures and economically mines considerable amount of deep geothermal energy from low permeability rocks[2].

Deep geothermal energy has several advantages, including high stability, continuous availability, and high utilization efficiency. EGS technology, which aims to mine and use the thermal energy contained in underground low-permeability crystalline hot dry rocks, has become the main direction of many countries' new energy development. At present, EGS is still at the demonstration phase. The coming ten years will be the key period for its development. The Geothermal Roadmap Report by the International Energy Agency (IEA) suggests that governments of all countries offer continuous and sufficient resources for R&D and demonstration so as to build and operate at least 50 EGS pilot plants in the next ten years. It is expected, by 2020 , major breakthroughs might be achieved in EGS engineering design and development and the demonstrative exploitation of geothermal energy from hot dry rocks realized. Fully developing and utilizing geothermal resources to partly substitute fossil energy sources such as coal and petroleum can not only reduce environmental pollution, but also ease shortage of fossil energy such resources as coal.

2. Recent progress in the world

Deep geothermal resource is a green renewable energy source with huge potential in future energy supply and CO_2 emission reduction. It has been taken seriously by most countries in the world. In recent years, the international community has made more and more urgent calls for EGS development. In addition to making huge investments in its research, countries such as the US, Germany, France, Australia, and Japan have built a group of experimental EGS projects.

According to the estimation by United States Geological Survey (USGS), the potential enhanced geothermal resources available for development in the US range from 100 GW to 500 GW. The United States Department of Energy (DOE) is increasing its financial budget for geothermal energy year after year. In April 2013, the first commercial EGS project in the US, Desert Peak, realized grid-connected power generation, which increased the installed capacity of the previous Desert Peak geothermal power plant by 1.7 MW. Other EGS projects backed by DOE include the Calpine Demonstration Project in Middle-town of California and the AltaRock Demonstration Project near Newberry Volcano of Oregon[3]. The US has also implemented demonstration projects in using CO_2 as a working fluid and generating power by using the joint sources of solar energy and geothermal energy[4].

Australia is one of the most active countries in carrying out EGS study. The Australian Government gives preferential policies to geothermal technology development. Now, Australia has founded the National Geothermal Energy Organization and several joint-stock geothermal companies, which carry out field tests of developing deep geothermal resources by using EGS technology in some key areas of Australia. The Australia Geodynamics Co., Ltd. runs the world's largest EGS project in Cooper Basin, which is doing experimental development. The company announced in May 2013 that its 1 MWe Habanero demonstration plant has successfully realized EGS power generation. Australia takes CO_2-EGS research and development very seriously. It has invested 18.30 million Australian dollars to have a geothermal energy center established in the University of Queensland, mainly for the relevant research and development.

Countries such as Germany, France, Britain, and Switzerland have carried out EGS study since the 1970s and 1980s. One of the representative projects is the Soultz Project at the border between Germany and France. This project has accumulated complete EGS development experience, making it an EGS demonstration project and training base of Europe. The sixth framework program of EU (EU FP6) (2002–2006) subsidized ten EGS projects. EU FP7, The European Strategic Energy Technology Plan (SET-Plan), and Europe Geothermal Energy Industry Association have given joint subsidies to the research, development, and innovation of some key geothermal energy technologies.

Japan started EGS research and development almost simultaneously with Europe and the US. Its Sunshine Project in 1974 and New Sunshine Project in 1993 carried out deep geothermal resources survey and prospecting, and hydrothermal dynamic research. In recent years, the Japanese Government has stepped up support to EGS by carrying out overall geothermal survey and prospecting, and financing or subsidizing geothermal research, development, experiment activities.

Turkey, Kenya, and Indonesia are also major countries in geothermal resources development and utilization[5]. However, in developing countries and emerging economies, geothermal resources have not been under large-scale development and utilization due to technological and economic limitations.

3. Advantages of China

China mainly develops and directly uses medium and low-temperature geothermal energy (<150°C). Its total thermal energy utilization volume ranks first in the world for the last 20 consecutive years. However, its geothermal power generation lags behind and only ranks 18th in the world. Without any EGS experience, China fails to make sufficient initiative investment in geothermal power generation and EGS. It has not yet carried out hot dry rock prospecting, development, and demonstration project. It does not have a national base and facilities for hot dry rock technology research and development. It is still doing basic research in utilization of geothermal energy by using CO_2 as a working fluid.

Currently, CAS, universities, the Ministry of Land and Resources are doing the relevant research. Their efforts focus on geothermal resources prospecting and appraisal, interaction between EGS fluid and heat-storing rocks, heat exchange mechanism, and energy conversion mechanism and technologies. CAS is a unit engaged in geothermal resources prospecting and appraisal, and the relevant research and development of geothermal energy utilization technologies. It has taken the lead in China to complete the hot dry rock resources appraisal and has done basic research in EGS technology. In a word, CAS has comprehensive advantages in research and development of deep geothermal energy utilization.

4. Future landmark goals and results

Geothermal energy is the third largest renewable energy resource. Now, it accounts for 0.5% of the total primary energy supply in the world and 3.9% of the total renewable energy supply. In areas teeming with geothermal resources, geothermal power generation has a very competitive cost. According to the Geothermal Energy Association (GEA) statistics, the installed capacity of the grid connected geothermal power generation in the world is about 11,224 MW[6]. In 2010, the power generated by geothermal energy in the world is twice the amount generated by solar energy.

According to the Geothermal Roadmap Report by IEA, heat supply and power generation by using geothermal energy will increase at least tenfold from 2011 to 2050[7]. If a series of actions are taken to encourage the development of the idling geothermal resources and new technologies, geothermal energy will contribute 3.5% of global power generation and 3.9% of global heat supply (excluding ground source heat pump) by 2050, compared with current 0.3% and 0.2%, respectively.

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Graphene: A New Potential Material of “Post-silicon Era”

Graphene triggered a global research upsurge since the researcher in the University of Manchester exfoliated it from graphite through “scotch tape” method in 2004. Graphene is regarded as a new potential material in the “Post-silicon Era” for making nano-sized transistors and circuits. Breakthroughs in this regard ensued in just a few years. Many kinds of products made by graphene are available now, and industrialization of graphene is underway.

1. Major S&T connotation and significance

Graphene is a kind of new material composed by carbon atoms through sp2 hybrid orbital, which is featured by hexagon single-layer sheet structure resembling honeycomb lattice. A single film layer is 0.335nm thick and the total thickness of 200,000 such films together is equivalent to that of a single hair merely[1]. Thanks to the unique structure of graphene, it is characterized by extreme high mechanical intensity, super conductivity, thermal conductivity, elasticity, air tightness and other prominent performance. Under room temperature, the strength of graphene is 100 times of that of steel, the electron mobility of graphene is 100 times of that of silicon, and the current density is 1,000,000 times of that of copper[2].

According to the Moore's Law, the amount of transistors that an integrated circuit can accommodate will double every other 18 months and the performance of transistors will see one-fold upgrade, also. But, the traditional silicon chip has its physical limits. Though the leading processing will extend the life cycle of silicon chips, it will surely come to an end because its size can't be reduced anymore[3]. It will become more and more difficult to etch integrated circuit on silicon chip. Consequently, people begin to search for alternative materials to take the place of silicon chip. Represented by graphene, the silicon alternative materials including the organic molecules, carbon nanotube, molybdenite and III-V group compounds will go beyond silicon in respect of physical limits and create chips that are smaller, faster and stronger[4].

2. Recent world progress

EU, US, South Korea, and UK invest a great amount of capital into the scientific and commercialization research of graphene. In 2013, the graphene research project headed by Sweden Chalmers University of Technology distinguished itself from the Future and Emerging Technology (FET) projects with the largest fund scale of EU up to now and gained a 10-year supporting fund amounting to Euro one billion[5].

The most important reason that can explain the rapid R&D progress of graphene is that the high-grade graphene can be acquired in lab through the relatively simple and inexpensive ways. Up to now, the scientific research teams all over the world have conducted a great amount of research in respects of preparation methods, property research and applications. The low-cost, large-scale and repeatable graphene preparation technologies are the key to the industrialized application of graphene. The breakthroughs in this regard will drive revolution of new technologies in such fields as information communication and energies. Table 1 shows the major preparation methods and existing limits with them. In addition, such preparation methods as molecular beam epitaxy and laser ablation also see some applications[6].

3. Advantages of China

China is at the forefront of graphene SCI paper quantity, so is the case with research level. Graphene preparation methods and applications have always been the R&D focus of China. But China still faces great challenges. Application of patents in relation to graphene are mainly performed in US, Japan, China, South Korea and the Europe. China and South Korea are rising stars in the technology field of graphene and the patent application quantity grow rapidly in recent years[7]. Many teams of the Chinese Academy of Sciences (CAS) are engaged in graphene research and a series of achievements have been achieved in succession in preparation methods and application research. Some efforts have reached the international level.

4. Symbolic target and achievement in the future

Graphene sees wide application research in the field of electronics (or electronic devices) and photonics (or photonic devices). The foremost point of market application of graphene is probably the transparent conductive film products. Touch screen is one of the most typical applications of graphene. Touch screen, electronic paper, organic light emitting diode (OLED) and other electronic devices need a relatively lower film resistance and higher light transmittance. Graphene can meet the demands for both electrical and optical performance. What's more, its single-layer light transmittance reaches 97.7% and it becomes an excellent alternative for traditional indium tin oxide. Graphene boasts also outstanding flexibility and chemical stability, which are quite important properties for flexible electronic devices. It is estimated that such graphene products as touch screen, electronic paper and foldable OLED will be launched onto market around 2015.

The performance of transistor made of graphene increases when it decreases in size. Silicon material shows instability on 10nm dimension. Graphene can reduce the transistor dimension limit downwards to several nanometers.

Table 1 Major graphene preparation methods and relevant limits

Preparation method	Application direction	Limit
1 Mechanical exfoliation	Research, prototype, etc.	Low output and efficiency, for lab demands only
2 Liquid exfoliation	Coating, compound, ink, energy storage, biology, and transparent conductive layer	It is hard to remove completely the organic solvent and surfactant. The electrical properties are affected consequently.
3 Chemical vapor deposition (CVD)	Coating, biology, transparent conductive layer, electron, photon, etc	Great energy consumption and complicated process; graphene has defects, grain boundary and thick inclusion layer.
4 SiC epitaxial growth	Electron transistors, RF transistors, etc.	SiC wafer has a higher cost and can be prepared in a high-temperature environment (>1 000°C).
5 Molecular assembly	Nanoelectronics, etc.	Purity is low and output is relatively low

Application of graphene in high-frequency transistors faces the competition against compound conductor made by more sophisticated technology. It is estimated that the actual application of graphene in high-frequency transistors will be available after 2021. Silicon technology boasts still certain development potentiality for logic transistors. As there is no band gap in graphene, it will replace the current silicon technology by 2020 probably.

Graphene photodetector is one of the optical devices with the most active research activity. Compared to semiconductor photodetector, graphene boasts a relatively wider spectral range and can detect infrared or even ultraviolet. As graphene is too thin, its effective detection area is small. Thus, it is weak in terms of light absorption and slow in terms of response. Considering the max. operating bandwidth of germanium photodetector, graphene photodetector will become competitive probably by 2020 or so.

The operating bandwidth of silicon optical modulator is quite narrow, approximately 50 GHz merely. But, graphene is able to absorb a wider spectral range and features by extremely high response speed. It can effectively improve performance of optical modulator and fulfill an operating bandwidth of 50 GHz or higher. The relevant achievements will probably be available after 2020[8].

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Green Intelligent Manufacturing Technology to Trigger Overall Industrial Revolution

1.Main scientific connotation and significance

As the material basis and industrial backbone of national economy, manufacturing is the engine powering the high-speed economic growth and an important guarantee for national security. It is also the basic carrier of science and technology and an important indicator of national economy and overall national strength. Manufacturing plays an important role in national economy and has always been an important strategic component of national economy for both developing and developed countries.

The advanced manufacturing technology that is mainly oriented to becoming "green" and "intelligent" is generated by the sustainable merging of the relevant technologies such as traditional manufacturing technology and information technology. During its rapid development, it constantly merges with material technology, biological technology, and nanotechnology. The advanced manufacturing based on the advanced manufacturing technology is at the high-end of the industrial value chain and features high technological content, high added value, low energy consumption and low pollution. It shoulders the important task of providing equipment, appliance, and detecting instruments for all sectors of the national economy and all disciplines of sciences, making itself "an enabling technology" on which the development of national economy, science, and technology rely[1]. Integrated research of intelligent manufacturing technology is a core content in the development of high-end equipment manufacturing and a certain step for promoting China's transition from a major manufacturing nation to a powerful manufacturing nation.

Informatization of manufacturing technology brings along innovations on technology R&D process, product design approaches and tools, management mode, and manufacturing mode. It realizes digitalized design, network-based manufacturing, and agile manufacturing of products, and rapidly responds to market changes and customer demands.

Automation of manufacturing technology gives rise to efficient and reliable automatic equipment and flexible production line, which will materialize automatic, flexible, and agile manufacturing.

Intelligent manufacturing technology adds better judgment and adaptation ability to manufacturing process, upgrades product quality and productivity, and will notably cut down material consumption, energy consumption, and emission in manufacturing process[2].

Ten years from now, most products will be recyclable and easy to dismantle. The parts or the entire set can be retrofitted and recycled. Green products may become the mainstream in commodity market worldwide[3].

2. Recent world progress

Although knowledge-based economy has emerged, manufacturing remains a main carrier in the whole world, including developed countries/regions such as the US, Japan, and Europe. Manufacturing still plays an extremely important role in the national economy of developed countries. In particular, after experiencing the financial crisis, Western countries have one after another put forward "reindustrialization", as a result, manufacturing tends to flow back to the West. The US, Japan, and Europe have actively forged development strategies, development programs , and the relevant supporting policies to guide and promote the healthy and rapid development of their advanced manufacturing technologies and the relevant industries. They aim to grab the high-end value chain of global manufacturing, lead technical advancement of global manufacturing, and continue controlling the entire manufacturing industrial chain through production mode reform and standard establishment.

In technology field, take the more and more globally popular 3D printing technology for example. 3D printing technology has obvious advantage in flexibility of manufacturing and efficient use of raw materials and is especially suitable for small-batch and customized processing and manufacturing of the products with complicated structures. It has made considerable progress in the industrial application market and personal consumption market. The demand for customized medical apparatus and instruments is the advantage of 3D printing technology. In the US, exoskeleton is produced by 3D printing technology to improve the movementcapable of disabled children. A two-year-old girl for the first time is able to raise her arms for play. Aerospace industry is one of the most promising fields for the application of 3D printing technology. For example, NASA is cooperating with enterprise partners to experiment 3D printing technology in microgravity environment. In consumer electronics and automobile industries, 3D printing technology is mainly used for prototype manufacturing and mould development. Manufacturers such as GM, Hyundai, and BMW have applied 3D printing technology to new car R&D[4].

3. China's advantages

In 2010, the Chinese manufacturing accounted for 19.8% of the world, making China the world's largest manufacturing nation[5]. Through the implementation of several "Five-Year Plans," China's manufacturing has made rapid development, achieved a number of fundamental research achievements, acquired some advanced manufacturing technologies whose absence had long been restraining China's industrial development, and managed to produce a group of high-end core equipment that had to be imported before and had affected Chinese industrial safety for a long period of time. China has carried out research and application demonstration targeting on some key and general technologies for green manufacturing,built a group of national R&D bases in the relevant fields, and cultivated a large group of high-tech talents that are engaged in long-term technology research and development. In cultivating and forming strategic emerging industry clusters, it is hopeful that China can take the lead to make breakthroughs in the technology for building the information perception space, technology for processing mass manufacturing information, technology for achieving manufacturing informatization and automation in ubiquitous information perception space, and technology for achieving man-machine behavioral cognition and interaction[6].

The Chinese Academy of Science has certain strength in green intelligent manufacturing. It has founded some relevant research institutes in Shenyang, Beijing, Chongqing, Ningbo, and Hefei. Shenyang Institute of Automation is the cradle of China's robot technology, and it is the supporting institution for nine national, provincial, and ministerial key laboratories and engineering centers, including the National Engineering Research Center on Robotics and State Key Laboratory of Robotics[6]. Institute of Process Engineering is dedicated to the basic and application research of the green process of large-scale resources transformation, utilization, and substitution[7]. Chongqing Institute of Green and Intelligent Technology has made scientific and technical deployment in electronic information, advanced manufacturing, and ecological environment[8].

4. Future indicative goals and achievements

In the field of intelligent manufacturing, the man-machine-merging intelligent manufacturing mode will be the basic feature of the development of intelligent manufacturing technology. Cloud computing and sea computing technologies will lead the advent of the new modes of manufacturing information processing. Ubiquitous information perception will offer new information support to intelligent manufacturing. Parallel management and visualization of manufacturing technology will provide new digital means for manufacturing. Innovation on manufacturing service will offer new channels for manufacturing upgrading and transformation.

In the field of green manufacturing, through green technology upgrading of the process manufacturing for large-scale transformation and utilization of mineral resources, petroleum and gas resources, and biomass resources, innovative breakthrough has been made in the green process of substance conversion and in engineering. In key areas such as new reaction medium substitution, efficient catalysis, process intensification, and secondary resources cycle, efforts will be made to upgrade resources utilization rate, cut down energy consumption, and reduce waste discharge by a large margin. The product green design and full-life-cycle assessment system will be widely used. Additive manufacturing (3D printing technology) and remanufacturing will be popularized.

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New Reproduction Mode Based on Stem Cells Will Emerge

Stem cells have great potential for disease treatment and drug R&D due to their proliferation and differentiation capabilities, especially for currently incurable diseases, construction of tissues & organs, and body injury repair, etc.

In the past few years, infertility has increased year by year, most of which cannot be cured currently. Whether stem cells can be a solution becomes a new concern of researchers. It is expected that stem cells can be induced in vitro to differentiate into germ cells, allowing patients to get healthy sperms or eggs through artificial methods. The breakthrough in this field may give rise to a new way of reproduction.

1. Current status of international research

Most somatic stem cells can only differentiate into specific cells for certain tissues. Although germline stem cells discovered recently may differentiate into germ cells, relevant studies (especially the female germline stem cells) are still in infancy and it is hard to obtain sufficient cells for follow-up studies in vitro. Theoretically, embryonic stem cells (ESCs) can differentiate into all tissue cells, including primordial germ cells (PGC), which may further differentiate into mature sperms or eggs. Therefore, ESCs become the ideal stem cells for relevant researches.

Researchers started efforts to induce ESC to differentiate into germ cells several years ago, and have achieved a series of breakthroughs. In 2003, two research teams from the University of Pennsylvania and Mitsubishi Life Science Institute reported the derivation of oocytes[1] and spermoblasts[2] from mouse ESCs, making it first known to all that pluripotent stem cells may be used to build male and female gametes. In 2004, the fertilization ability of germ cells differentiated in vitro was first verified. Research team from Harvard Medical School proved the fertilization ability of "artificial sperms" of mouse[3]. In 2006, a research team from Goettingen University and Newcastle University used mouse ESCs to create "artificial sperms" and finally cultured seven offspring mice, proving that artificial germ cells may be used to produce offspring. However, these mice died within five days to five months due to health problems (normal lifespan: about two years)[4], making normal offspring culturing a bottleneck of the research. In 2011, a research team from Kyoto University and Japan Science and Technology Agency (JST) broke the bottleneck by transforming mouse ESCs and induced pluripotent stem cells (iPSC) into primordial germ cells, thereby obtaining normal sperms to culture mouse pups. These offspring remained alive and healthy after one year and gave birth to the next generation[5].

Although these studies proved that pluripotent stem cells can regenerate functional male germ cells, construction of functional female germ cells remains a blank. In 2012, the research team from Kyoto University and JST again made a breakthrough by constructing fertile oocytes with mouse ESCs and iPSC, and transplanting two oocytes into female mice after in vitro fertilization. Both of the oocytes gave birth to healthy offspring[6] and the achievement was rated as the TOP 10 Scientific Breakthroughs by *Science* magazine.

After more than a decade of researches, the potential of pluripotent stem cells in mice to generate functional germ cells in vitro has been proved. Development mechanisms of germ cells are also basically understood. If relevant technologies can be used to construct human sperms and eggs through artificial methods, it will bring hope to infertility patients and give rise to a new way of life reproduction.

2. Development status in China

Although less attention is paid to inducing stem cells to differentiate into germ cells, a lot of researches have been done in reproduction-related field and several breakthroughs are made. In 2009, a research team from Shanghai Jiaotong University separated germline stem cells from female adult mouse[7], overturning the long-standing theory that "the number of eggs in a woman has been determined during her fetus stage". Despite some doubts about the theory, it created a new way to explore the mysteries of life. In 2012, two research teams from CAS again made a breakthrough by building androgenetic haploid embryonic stem cell lines via nuclear transplantation, and proved that these cells could replace sperms for fertilization and culturing healthy offspring mice[8,9]. Compared to germ cells derived from stem cell differentiation, the "artificial sperms" are capable of continuous passage. Via a series of steps in vitro, these "artificial sperms" can widely used in more fields.

The above results also laid a foundation for the treatment of reproductive-related diseases. In 2013, China included the research on germline stem cells (research on the transformation mechanism from spermatogonial germ cells to germline stem cells and germ cells) in its national major scientific research program, which shows the importance of relevant areas and will promote more progress in these fields.

3. Problems and prospects

Despite great prospect for applications, the research is just a beginning. Firstly, in follow-up studies, lots of researches shall be done to verify the stability and defects of relevant technologies, plus an urgent bottleneck to be solved, that is, how to complete the meiosis in vitro during transformation from primordial germ cells to germ cells. Only by controlling the whole process of stem cell differentiation in vitro can we finally obtain high-quality germ cells. In the ongoing studies, induction in vitro is only used to induce ESCs into primordial germ cells. The following differentiation of germ cells is done by transplanting them into the testes or ovaries.

Secondly, technology tested in mice may not be fully applicable to human. A series of new issues are likely to be resolved by researchers. Currently, few breakthroughs are made in human-related fields, except that published by a research team from Stanford University in *Nature* in 2009, where human embryonic stem cells were used to cultivate artificial sperms in vitro[10].

Finally, even if there is a stable and mature technology, the "unimaginable" ethical issues will be the biggest obstacle to its application to human. For example, if a woman is able to generate sperms with her own cells, she may give birth to child without a man. Besides, if artificial insemination can be done simply with "artificial sperms" and "artificial eggs", an "artificial baby" may be created in the laboratory definitely. It will undoubtedly disrupt the normal reproduction mode.

Therefore, if the above technical bottleneck is solved under a scientific and reasonable supervision, stem cells will play a significant role in the reproductive field in future.

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Breakthroughs are Expected in Personalized Diagnostics and Treatment Techniques

Personalized Medicine Technologies based upon Systems Biology are now embracing rapid development. Precise and timely monitoring of the development process of critical diseases such as tumors allows us to perform precise classification of disease-associated molecules and personalized treatment, and to promote the medical pattern to transform from treatment-based clinical medicine to early detection- and intervention-oriented health sciences.

1. Scientific connotation and significance

The concept of "Personalized Medicine" was first brought up in the 1970s. Targeting therapy for tumors, an example of personalized medicine, made its first official appearance in the late 1990s. In 1997, *Science* magazine defined "personalized medicine" as "application of medication tailored to patient's genetic components". In the beginning of the 21st century, development of omics technology greatly contributed to the progress of personalized medicine. With breakthroughs of key technology and penetration of scientific research, we gained a more profound understanding of disease diagnosis and pharmacotherapy thereof, and came up with the technology for personalized diagnostics and treatment by employing research results from polymorphic analysis of genomes, pharmacogenetics and pharmacogenomics.

Research shows that major chronic diseases such as cancers, diabetes and neurodegenerative disorders are caused by the interactions between multiple genes and external influences, and the traditional "one-size-fits-all" approach adopted in the past has led to poor effectiveness of drugs and low cure rate in such cases. Whereas personalized medicine stemmed from systems biology is built on the basis of profound understanding of complex mechanisms of diseases, an approach allows risk assessment and diagnosis of disease through identifying and detecting genetic predisposition of individuals, thus helping us choose the optimal plan for prevention and treatment. The therapeutic effects are therefore greatly improved by adopting such tailored methods. Personalized diagnostics and treatment technologies, which are of important value in the aspect of drug development, medical diagnosis and clinical study, help researchers come up with more effective diagnostic methods. In this way, not only does the medical profession get favorable social and economic benefits, but also the public burden of disease is reduced with the public's health and life quality improved.

2. International development status

(1) Policy planning

Personalized medicine has become the hot field that every country keeps a watchful eye on. The US NIH Research Project Grant Program, the Strategy for UK Life Sciences, Development of Medical Science in the Russian Federation for the period up to 2025 and Canada's "e-Health" Program have all listed "Personalized Medicine" as one of the focal fields to work on; in addition, the European Science Foundation (ESF) published a report on personalized medicine for the European citizen in December 2012, which conducts a macroscopic planning on the development of personalized medicine in Europe[1]; the UK Medical Research Council and Canadian Government also respectively invested £10.6 million and $13.7 million into personalized medicine program[2]; the UK National Health Service is planning on promoting a genome sequencing program to perform genome sequencing on patients with cancers, rare diseases and infectious diseases, thereby laying a foundation for personalized medicine for such diseases.

(2) Primary domains of research

Adjust the therapeutic regime to suit patients with different characteristics. In recent years, the development of genome sequencing techniques has enabled doctors to classify patients with the same disease using results from clinically effective methods. They can confirm specific subtypes of diseases sensitive to certain therapeutic methods and drugs with a train of new gene molecular markers. These markers, serving as the base for the newly emerged gene molecular detection, can be used for disease risk assessment for patient, decision of what drugs are suitable for which patient, as well as determination of appropriate dosage according to patient's metabolic reaction, etc. For example, we can estimate the possible results that may be obtained from certain patients applying certain drugs, figure out which group of patients may suffer from serious adverse events when taking certain medicines or different dosages of a medicine, determine the optimal dosage of drugs with vastly-diverse therapeutic effects, assess the degree and development of disease, explore alternative measures for clinical effects and determine which group of patients may benefit from certain preventive measures.

Targeting Therapeutics. Treat diseases arising from gene mutations with the specific physiological mechanisms about how targeting therapeutics work on human body. These drugs are particularly effective against single-gene disorders as they are designed to cure single gene mutation. Genome technology can detect new disease markers, thus booming the new targeting therapies. This is particularly the case for targeting therapeutics as they have been used in combination with gene diagnostic tests. Nonetheless, most of the diseases we deal with today are polygenetic diseases, the so called complex diseases (e.g. cancers, neurodegenerative disorders and diabetes), which makes it necessary to further improve target therapeutic effect against diseases of such kind.

(3) Products and markets

Commercialization of personalized medicine is being stepped up by development of DNA sequencing technology, support and attention from government, rapid development of academic research, constantly increased investment as well as accumulation of clinical data, thus giving rise to multiple personalized medical products. Ever since listing of the first personalized drug, *Trastuzumab* (Herceptin®) in 1998, the US Food and Drug Administration (FDA) has listed over 100 various personalized drugs, among which those for cancers have attracted most attention, wherein those for breast cancer are oriented; furthermore, cardiovascular diseases, infectious diseases and respiratory diseases have also gained extensive attention in recent years. In June 2013, the US FDA approved the first HCV gene detection reagent developed by Abbott Laboratories, which is used to distinguish seven different genotypes of *Hepatitis C*, thereby helping medical staff determine the most suitable therapy.

A report from BCC Research, a market research firm, showed that the global market for personalized medicine technologies was estimated to expand from $14.4 billion in 2009 to $29.2 billion in 2014 at the annual growth rate of 15.2%[3]; Price Waterhouse Coopers predicted that personalized medicine would grow to a $42 billion market by 2015 in the United States alone. Right now, personalized medicine is growing at a compound annual growth rate of 10%, which makes it the definite hot territory for the eyes of pharmaceutical and diagnostic technology companies[4].

3. Research progress in China

China has also made significant progress in personalized medicine for the past few years: in late 2012, a number of institutions worked together to come up with the liver disease spectrum covering 103 types of liver diseases, which identified the clinicopathological features for all types of liver diseases in China for the first time and hierarchically screened the same, thus laying a foundation for personalized medicine for liver diseases; in 2012, Professor MA Jun's Team from Cancer Center, Sun Yat-sen University and West China Hospital, Sichuan University co-discovered a set of molecular markers consisting of five microRNAs with good predication capability for therapeutic effects, hence laying the foundation for personalized medicine for nasopharyngeal cancer; On January 8, 2013, high precision HB-VDNA detection technology was achieved to inhibit or remove replication of viruses to the largest extent, being the latest achievement in personalized medicine for liver diseases in China. The Chinese Academy of Sciences (CAS) has carried out a variety of researches in the field of personalized diagnostics and treatment with yielded substantial achievements, mainly reflected in technologies including light-controlled drug release, microfluidics, single-cell sequencing, and iPS cells conversion. In April 2013, CAS' Strategic Priority Research Program, "Personalized Medication – Development of New Benefit-All Drugs based upon Subtypes of Disease Molecules", entered the organization & implementation phase, which is expected to help drive the research in personalized medication forward.

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Application of Stem-Cell Technique for Diagnosis and Treatment of Cancer and Other Major Chronic Diseases

Stem-cell technique has huge potential in diseases treatment. Current clinical trials of stem cells involve a wide range of diseases, including bacterial and fungal diseases, behavioral and psychiatric disorders, blood and lymphatic disease, cancers and other tumors, digestive diseases, heart and blood disorders, immune system diseases, oral and dental diseases, muscle, bone and cartilage diseases, neurological diseases, and reproduction-related diseases.

1. Stem cells involve in the diagnosis and treatment of neoplastic diseases

Cancer is one of the major diseases that threaten human life. Due to a lack of systematic understanding of its occurrence and development mechanism, there is no effective cure for it now. With the deepening research on stem cells, researchers found that some tumor cells are quite similar to stem cells. In 2001, Professor Weissman of Stanford University initially created the concept of cancer stem cell (CSC)[1].

In recent years, CSC researches have got more attention, which are included in national stem-cell research programs. NIH of the U.S. keeps funding the CSC researches, up to more than $30 million/fiscal year from 2010 to 2012. In 2007, Canada established the Cancer Stem Cell Consortium (CSCC), which, in 2012, funded a large-scale CSC project to develop CSC-based cancer therapies.

Under the support of national policies, lots of researches have been carried out, focusing on basic research areas, including the identification of CSC markers for identification, separation and cell lines establishment of CSC; and the mechanism of CSC in tumor oncogenesis, recurrence and metastasis. In addition, studies have been conducted to make use of CSC targets to develop new anticancer drugs and diagnostic techniques.

(1) CSC research helps understand the mechanism of oncogenesis and development. CSC has been found in a variety of solid tumors. In August 2012, three articles published on both *Nature* and *Science* confirmed the presence of CSC in skin cancer[2], colorectal cancer[3] and cerebral cancer[4]. Later, German scientists confirmed that some CSC that may trigger tumor metastasis exists in breast cancer[5]; U.S. scientists first discovered bone CSC[6]; and a Japanese research team initially established the stable cell lines for colon CSC, laying a foundation for the treatment of colon cancer[7]. These findings indicate that CSC is tightly correlated to oncogenesis, recurrence and metastasis. Therefore, in-depth exploration of CSC will allow us to gain a systematic understanding of neoplastic diseases. CSC markers and key targets in the regulatory pathways may be used for the R&D of new anticancer drugs.

Upon confirming the role of CSC in various tumors, researchers further explored its mechanism. In 2012, Swiss scientists discovered that tumor metastasis cannot do without CSC and its success is related to the microenvironment[8]; Dutch researchers also found intestinal adenomas suppressors which inhibit the growth of intestinal stem cells[9].

(2) Develop CSC-based cancer therapies. Based on the basic CSC researches, researchers began to develop CSC-based cancer therapies and have achieved some preliminary results. In 2012, U.S. researchers successfully made CSC in mice into tumor vaccines and confirmed the immunogenicity of CSC, which can stimulate the production of tumor antibodies in mice[10]. Researchers from Canada also screened a CSC-targeted drug for cancer treatment, which weakens the self-renewal capacity of CSC by promoting their differentiation, thus inhibiting the further tumor growth and metastasis[11]. In addition, a series of CSC-targeted therapies have been used in clinical trials. Rough statistics show that there are about 200 clinical trials, among which therapies for leukemia stem cells account for more than 50%.①

①From the databank ChinicalTrials.gov.

2. Application of stem cell technique in the treatment of degenerative and metabolic diseases

Neurodegenerative diseases (e.g. Parkinson's disease) and metabolic diseases (e.g. diabetes) have become the major diseases threatening human health, which cannot be cured effectively now but can only be controlled via some measures.

Most of these diseases are caused by lesions of some functional cells that prevent them from functioning properly. For example, Parkinson's disease arises because some nerve cells in the nervous system are damaged; while diabetes results from the dysfunction of pancreatic β cells, in which case insulin cannot be secreted as usual. Ideally, these diseases can be treated by replacement of the damaged cells. The potential of stem cells differentiating into tissue cells may realize the purpose, thus bringing hope for treatment.

In addition to direct treatment of above diseases via stem cell transplantation (SCT), pluripotent stem cells, especially iPSC-based disease models are also used for the research of disease mechanisms and drug screening, which helps solve the problem that large amount of disease-related cells cannot be obtained from the patient for pathological studies, particularly the research and treatment of brain diseases.

(1) Treat degenerative diseases and metabolic diseases by SCT. In this field, researchers have conducted a series of attempts and achieved positive results in laboratory studies and clinical trials.

In 2011, U.S. researchers transformed human embryonic stem cells into dopamine neurons and transplanted them to the brains of rats and mice to eliminate the symptoms of Parkinson's disease[12]; in 2012 and 2013, two research teams from Japan[13] and U.S.[14] also used human embryonic stem cells to produce dopamine neurons, and verified its normal effects inside monkeys with Parkinson's disease. Regarding diabetes treatment with stem cells, Canadian and U.S. researchers restored the insulin secretion of mice through transplantation of human embryonic stem cells in 2012[15]; and in 2013, U.S. scientists treated type I diabetes of mice with drugs combining stem cell transplantation[16].

(2) Use iPSC to build disease models and study disease mechanisms. In this field, researches on neurodegenerative diseases are of special concern. In 2012, U.S. researchers cultured the neurons of patients with Parkinson's disease based on iPSC and found that, the genetic mutation sites varied with patients[17]. Another research team has constructed an iPSC-based disease model of Alzheimer's disease (AD) and observed its pathogenesis[18].

3. Development status and future trends in China

In 2013, China made a special plan for CSC in its "973" Program and other major research programs, focusing on the study of basic CSC biology, which is also included in CAS's strategic pilot projects on stem cells and regenerative medicine, showing the importance of this field.

According to incomplete statistics, China published nearly 300 CSC papers in 2012, secondary only to the U.S., proving Chinese research strength in this area. In 2013, researchers from the Institute of Zoology, Chinese Academy of Sciences and Peking University uncovered the mechanism of CSC in metastasis of colorectal cancer, and recommended a potential therapeutic target for its treatment[19]. Researchers from Third Military Medical University revealed the signaling mechanisms of self-renewal and tumorigenic potential maintenance of CSC[20].

With regard to the application of CSC treatment, we only carried out a few clinical trials and the Clinical Trials database included those conducted by the Huashan Hospital, where glioma stem cells were used to prepare vaccines against malignant glioma. Currently, the trials have entered phase II.

Researches on stem cells related to neurodegenerative diseases also achieved a series of breakthroughs. In 2012, researchers from the Institute of Biophysics, CAS took the initiative to combine the iPSC and targeted gene modification technology, demonstrating the degeneration of neural stem cells in Parkinson's disease throughout the aging process, providing a new potential target for the prevention and treatment of the disease[21].

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Designer Breeding by Molecular Modules is a Novelbreeding Technology to Create a New Generation of Agricultural Organisms

Owing to the rapid development of life sciences and the wide application of information technology in agriculture during recent years, the world has attached great importance to the use of molecular breeding techniques such as marker-assisted selection and transgenic breeding for improving agricultural production, ensuring food safety, and supporting research and development at the frontier of modern agricultural science and technology. Because important agronomic and economic traits in animals and plants are complex and generally controlled by quantitative trait loci derived from natural variations, the genetic regulatory networks are often characterized by modular features. The existing molecular breeding technologies modify specific traits in a limited range and space, which cannot to meet the demand of complex traits as the target of molecular breeding by design (MBD). Discovery of novel targets for multi-genes by modular design becomes the direction of future development[1]. Thus, a new breeding concept of designer breeding by molecular modules (DBMM) was proposed by researchers from the Chinese Academy of Sciences (CAS) in 2008, in order to develop a new generation of biological breeding technology for the future.

1.The meaning and significance of DBMM

Based on the development of omics, molecular biology, systems biology, synthetic biology and computational biology, DBMM represents a new breeding theory and approach for creating superior animal and plant varieties. DBMM mainly involves the following three steps: (1) exploration and functional interpretation of molecular modules controlling complex traits. That is, to explore the functionally important genes and their allelic variations that control complex traits in agricultural organisms, and to interpret functional modules capable of genetic manipulation in the regulatory networks; (2) elucidation of the mechanisms of molecular module coupling. The means of computational biology and synthetic biology are used to achieve a synergic and coherent coupling of molecular modules and to analyze the potential regulation of module-module interactions for complex traits; theoretical modeling and functional prediction are carried out to achieve such a coupling of the molecular modules with the desired genetic background in association with the regional environment; and (3) directional modification of complex traits through a multi-module genome-wide assembly optimization and an effective breeding scheme design[2–4].

DBMM is a novel and unique combination of cutting-edge developments in life sciences associated with breeding practices. DBMM will promote major theoretical and technological breakthroughs of MBD and lead a new direction in revolutionizing breeding techniques. Construction of an innovation system of DBMM will provide a novel strategy for plant and animal breeding, cultivate a series of new plant and animal varieties with superior traits (high yield, good quality, stable production, and high efficiency), and ultimately promote the development of strategic emerging industries of biological breeding in China. DBMM is of great strategic importance to improving integrated agricultural productivity, enhancing international competitiveness of agricultural products and ensuring food safety in China.

2. Research progress

DBMM is presently in an early stage of development. The existing studies of DBMM mainly involve initial researches for exploring important genes or QTLs and their allelic variants. A few genes and QTLs that control important agronomic traits (e.g., high yield, good quality, resistance to adverse factors, and high nutrient efficiency) have been identified and cloned in a number of valuable plant and animal species[3,5,6]. Relevant breeding simulation tools are increasingly developed and used. Computer software products and methods for simulating complex genetic models and breeding, including QuLine, QuHybrid, and QuMARS, have been developed one after another and used for comparative study of different breeding methods[5].

Presently, elite variety breeding for improving complex traits has not yet been achieved by a designer approach. However, both important research achievements and significant technological invention in recent years have provided a possibility for designer breeding by molecular modules. For example, introduction of the chromosome segment substitution 1BL/1RS, the natural breeding module from rye into wheat enables the breeding of a large number of high-yield, disease-resistant varieties. Elucidation of the genetic relationship between the genes of rice ideal plant architecture (*IPAI*) and grain width (*GW8*) with the microRNA156 lays a solid foundation for significantly increasing grain yield of rice (>10%). A variety of gibel carp, Zhongke 3, obtained through a dual mode of reproduction (gynogenesis and amphigenesis), represents a new nucleocytoplasmic hybrid clone variety and achieves an average increase in the yield by more than 20%[7].

3. Advantages in China

China has implemented the pre-deployment for DBMM. Several molecular design breeding projects are included in both the 973 and 863 programs, and relevant research has been carried out[8,9]. CAS researchers proposed and implemented the major research project of *Molecular design of important agronomic traits in wheat and rice and new variety breeding and extension* and the strategic priority research program of *An innovation system of designer breeding by molecular modules*. Implementation of the above programs contributes to the combination of a large number of internationally renowned research personnel and improves the framework of relevant disciplines, thus laying a solid foundation for further in-depth research and development.

China is one of the world leaders in crop genomics. Genome sequencing has been completed for a number of plant and animal species, e.g., rice, wheat, cotton, carp, grass carp, and goats. Platform construction of omics involving proteomics, metabolomics and phonemics has increasingly improved. Functional genomics research has reached the world's leading level, including the cloning and functional analysis of a large number of plant and animal genes with great application prospects, and construction of a large-scale rice functional genomics research platform such as a large-scale mutant library, a full-length cDNA library, and a microarray for genome-wide expression profiling. To date, a number of genetic population suitable for molecular design breeding have been established, such as the NAM group, the MAGIC group and the chromosome substitution lines.

4. Anticipated targets and outcomes

With breakthroughs of the DBMM technique, the genetic network of important agronomic and economic traits and their molecular module control theory in animals and plants will be interpreted and elucidated. Molecular modules responsible for important breeding value will be obtained and genetic manipulation techniques of multi-module coupling will be established to solve the bottleneck problems of the existing breeding techniques. Ultimately, a modern biological breeding innovation system from molecular modules to design elite varieties will be established, further achieving a synergic and coherent modification of complex traits and producing a series of new molecular designer types of plant and animal varieties with high yield, good quality, stable production and high efficiency.

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Bio-manufacturing Innovation Enabled by Progress in Synthetic Biology

The rapid growth of world economy is increasingly encountered by the limitations in the supply of food, energy and resources as well as the challenge of environmental protection. With an impressive economic growth rate over the past three decades, China is now facing these challenges even more seriously than other countries. Currently, China is striving to transform the traditional inefficient mode of production into a low-carbon, circular, and ecological economy for sustainable development based on technology innovation.

As a novel interdisciplinary academic field developed based on modern biology and systems science, *Synthetic Biology* integrates both knowledge and technology of various disciplines such as physics, chemistry, and information science and evolves a bottom-up strategy for the goal of synthesizing artificial life adapting the engineering concept of modularization and standardization as well as the theory of systematic design. Meanwhile, enable technology focusing on artificial synthesis and modification/recombination of DNA are developed for construction of biological parts, modules, and devices along with the establishment of chassis cells and other systems. Synthetic biology modifies the existing natural biological systems by using the parts and devices[1, 2], or creates "artificial lives" such as biological components and systems that have never existed in nature[3]. Through the extensive use of the theory and methods of synthetic biology in bioengineering and biological manufacturing technology development, a few of the enormous future promises that we might achieve includes:

— Breaking both the functional limits and the productive scopes of metabolism of living organisms. That may lead to the production of special products which are difficult to be produced efficiently in traditional manufacturing industry or even are rare or nonexistence in nature. And eventually, the development of bioeconomy[4] might be realized.

— Overcoming the high energy consumption and high pollution problems of the traditional manufacturing industry, and developing new energy sources, chemicals and materials necessary for human being in an advanced, efficient and environmentally-friendly manner. That may facilitate the transition of the manufacturing base of the economy from the petrochemical industry to a new mode of social and economic development characterized by efficiency, cleanness, resource conservation and sustainability.

To sum up, based on the rational design and creation of "artificial biological system", synthetic biology can realize the green manufacturing of products necessary for the society that may even change the traditional understanding about the advanced manufacturing technology[5].

1. Synthetic biology technology becomes the main impetus for innovations in biological manufacturing

Up to date, the researches in synthetic biology have been focusing on creation of new synthetic organisms, to design new and efficient living systems according to the demand of human being and to produce products and materials with ideal performance. In May 2010, J. Craig Venter Institute created the first bacterial cell with a synthetic genome, which represents an important milestone in the field of artificial design and construction of functional synthetic organisms[6].

The representative application of synthetic biology in pharmaceutics manufacturing is the success in production of the antimalarial drug precursor artemisinic acid in engineered yeast in 2006, achieved by the research team led by Jay D. Keasling from University of California, Berkeley. In the paper published in Nature on April 10, 2013, the research team reported that they had achieved the semisynthesis of artemisinin, which had become a milestone breakthrough in synthetic biology and biomanufacturing. Based on the research achievement, the pharmaceutical company Sanofi had launched the large-scale production of a partially biosynthetic version of artemisinin[7]. Paclitaxel (taxol), a terpenoid similar to artemisinin, is a kind of anticarcinogen sourced from plant. The scientists from Massachusetts Institute of Technology and Tufts University constructed the metabolically engineered *Escherichia coli* to produce taxadiene, an important precursor of paclitaxel, by using the synthetic biology technology and the yield has been increased remarkably than reported, which pushes forwards a stride for production of synthetic paclitaxel. In addition, researchers, both at home and abroad, have investigated in ginsenoside biosynthesis employing synthetic biology strategies and have achieved significant progress in understanding the key enzymes for biogenesis, which provides the important biological parts for biosynthesis of ginsenoside[9-11].

In the field of bio-manufacturing of energies and bio-based chemicals, the researchers from University of California, Los Angeles, engineered the biosynthetic pathway of amino acid of *E. coli* to make it more appropriate for production of long-chain alcohol fuels, which is the first successful example of biosynthesis of long-chain alcohol[12]. Comparing with ethanol, the long-chain alcohol has more carbon atoms and greater energy density, which is easy to be separated from water and is expected to be the ideal alternative biofuel. Keasling's group developed an engineered *E. coli* strain with the capacity for new biochemical reaction, which can produce the advanced biofuel directly from biomass, to produce the biodiesel and other important chemical products employing their fatty acid biosynthesis potential[13].

For the synthetic biology enabling technology, its rapid development and transformation towards broad applications will continue to promote significant innovations and industrial applications in the field of bio-manufacturing such as biorefinery and biomass transformation, biocatalysis and bioprocessing as well as modern fermentation and will greatly facilitate the development of the alternatives for fossil resources and industrial processes as well as the upgrade of traditional bio-industry[14]. It is expected that the United States of America will achieve a 20%–30% increases of fine chemicals produced by biocatalysis by 2020 and to substitute 30% of the traditional processes with biocatalyzed processes[15]. Europe plans to make a substantial progress in transformation into biotechnology-based society by 2025[16]. China plans to achieve an annual output value of RMB 750 billion in bio-manufacturing industry and, as the first step, make a significant progress in substituting petrochemical materials and traditional chemical process with bio-based products and bioprocess technologies by 2015[17].

2. A solid foundation and the bright prospect of the relevant researches in China

Over the past few years, a great deal of researches have been conducted in the fields of microbiology, metabolic engineering, genetic engineering, genomics, nanoscience, bioelectronics and advanced manufacturing, and a series of critical R&D platforms have been created. Along with the series of major conferences in the field of synthetic biology such as the XiangShan Science Conference, the Oriental Symposium, the Exploratory Round Table Conference (ERTC) and the Three-Country Six-Academy Synthetic Biology Symposium, communication and cooperation among scientists gradually nurtured the consensus, which ensured the quick development of the emerging discipline of synthetic biology. After continuous supporting the projects in the field of synthetic biology initiated in 2010, the Ministry of Science and Technology is, at present, planning the roadmap of developing synthetic biology in the following two decades and relevant research projects will be further deployed.

Since the implementation of the three phases of knowledge innovation programs, Chinese Academy of Sciences has developed a batch of key technologies in the field of metabolic engineering, biofuels, bio-based chemicals, industrial enzymes and bulk fermented products. Meanwhile, severalbio-manufacturing research teams with comprehensive and complementary cross-disciplinary structures including several key laboratories have been established as the foundation for the national scientific infrastructure. In addition, CAS Bio-industry Science-technology Innovation Union was established, which attracts a large number of enterprises interested in this field to set up the scientific and technological innovation funds.

At present, China has made substantial progresses in rapid and efficient synthesis of rare plant active compounds such as artemisinin[18,19], paclitaxel[20,21] and miltiradiene[22,23] with the chassis cell, as well as in the field of bio-manufacturing of chemical products such as butanedioic acid[24,25] and isopropyl alcohol[26]. However, the international competition is becoming more and more tense and critical in the field of synthetic biology and its applications in bio-manufacturing. Therefore, it is necessary to strengthen the strategic planning, continue to make efforts for scientific breakthroughs and to enhance the integration of resources for systematic development and to make a foundational, strategic and prospective contribution to the sustainable development of bioeconomy.

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The Earth System Science Research on the Tibetan Plateau is Expecting a Breakthrough

The Earth system science is a new research concept with which scientists can comprehensively understand the Earth and solve complex issues concerning resources, environment and the relationship between human and the Earth[1,2]. Since the 1990s, international communities have launched research programs on the interactions between the six spheres including atmosphere, cryosphere, hydrosphere, biosphere, lithosphere and anthrosphere, such as LOICZ, SOLAS, iLEAPS. Those programs have greatly advanced our understanding of the Earth system. The Tibetan Plateau where the interaction of the six spheres is the strongest[3], is extremely sensitive to external perturbations and crucial to impact the surrounding regions, and has become one of the key regions of international Earth system science research.

1. The Tibetan Plateau is a key study region where the Earth system science could make breakthroughs

Sensitive to interaction between the six spheres, particularly to the natural ecosystems, the Tibetan Plateau is an excellent natural laboratory to study Earth system science, and thus aspired to by almost all earth scientists internationally. It is expected in-depth research into this region will reveal the Plateau uplift process, environmental change and its impact on the global environment, particularly on the environment in East Asia, thereby helping appreciate many uncertainties in addressing climate change in the region. Besides, the grasp of uplift-related mechanisms and mineralization and proposition of new theories regarding the environmental responses to the Plateau uplift will help promote a comprehensive Earth system science study of the region, and thus providing solid scientific ground for the resources management and maintenance of sustainable development of the society in the Tibetan Plateau and surrounding regions.

2. The Earth system science research on the Tibetan Plateau will focus on the interaction between the six spheres

The Tibetan Plateau Earth system science research will focus on deep Earth processes and changes in the lithospheric structure impacting on the Earth surface system, as well as the interactions between the six spheres, their relationship with human activities, and environmental responses. The study of the interaction between monsoon and westerlies will be a major scientific focus and may lead to significant scientific breakthrough. In the deep Earth system, there are novel issues closely related to the Plateau uplift process, including the generation of the Yangtze and Yellow rivers, the initial collision between the Indian continent and the Tibetan Plateau and its evolution trajectory. Viewing from the perspective of the Earth surface systems, multi-phase water transformation and its impact on environment, particularly on the ecosystem, is a major issue that can contribute to scientific decision-making regarding multiple objectives including resource management, ecological protection and social development.

3. The Earth system science research on the Tibetan Plateau will promote scientific understanding of some significant issues which are related to social development

The progress of the Tibetan Plateau Earth system science will comprehensively promote current understanding of the environmental effects of the Tibetan Plateau on the surrounding Asian countries, confirm many uncertainties human are facing due to climate change, and provide scientific support to the sustainable development of resources and society in the Tibetan Plateau and surrounding regions.

(1) Studying deep Earth processes and lithospheric structure changes in the Tibetan Plateau will help monitor, predict, and warn earthquakes and other related natural hazards. The Tibetan Plateau is an excellent natural laboratory for the deep Earth processes research. Carrying out research into Earth system science on the Tibetan Plateau could ascertain Tethyan subduction orogeny process and India-Eurasia collision orogeny process, reveal crust-mantle interaction during those processes and its constraints on the uplift of the plateau, thus providing new opportunities to the development of plate tectonic theory. Earthquakes and other related geological hazards often cause serious social consequeces to the Tibetan Plateau and surrounding regions. Earthquakes occurred in recent years are closely related to the Plateau uplift process, including the Wenchuan, Yushu, Lushan and Dingxi earthquakes[4-6]. Studying tectonic movements over the Tibetan Plateau could help identify the mechanism of the earthquake and other related geological hazards in this region and its surroundings, and thus supporting scientific decision-making concerning prediction, prevention, early warning, disaster-mitigation and adaptation.

(2) Studying metallogenic mechanism in the collisional orogeny of the Tibetan Plateau could help establish metallogenic model and prospecting model, and improve the metallogenic prediction ability. Metallogeny of continents is an important research frontier in the contemporaneous metallogenic study. Its theoretical framework is conceived and established through gaining a deep understanding of metallogeny in the continental collisional orogeny. The Tibetan Plateau orogen, which is characterized by the occurrence of large-scale, intense and young mineralization as well as many types of large and well-preserved deposits, is regarded as an ideal natural laboratory for studying ore-forming process on continents and solving the issues mentioned above[7]. Progress in space-time structure and mineralization characteristics in subduction/collision metallogenic system could provide a theoretical basis for a potential major breakthrough.

(3) Studying the interaction of the six spheres in the Tibetan Plateau will benefit protection and improvement of its environment and ecosystem. The Tibetan Plateau uplift has changed atmospheric dynamics and thermodynamic conditions, forming a unique water-heat pattern that has an important effect on the climate system in China and East Asia. With global warming, the Tibetan Plateau holding the headwaters of many prominent Asian rivers and regional ecological security shelters will undergo significant change in the surface processes, thus bearing a direct impact on its environment and ecosystem and finally on regional economic and social development[8, 9]. Some important objectives related to this issue include the surface environment pattern, the multi-phase water transformation, spatial and temporal changes of ecosystems, adaptation options to global warming, and so forth. The progress of those studies targeting at those objectives will reveal tele-connections among atmospheric circulation systems, water circulation and environment changes, and establish some successful cases for the development in the environmentally and ecologically sensitive regions. Through the implementation of some major

national projects, such as the study of systematic differences of glacier status from region to region in the Tibetan Plateau and surroundings, and that of the Indian monsoon and westerly circulation from stable oxygen isotopes in Tibetan precipitation[10,11], significant progresses have already been achieved, and significantly contributed to the environmental planning and protection.

4. The trend and future of international research progress

As early as in the second half of the 19th century, some western explorers and scientists conducted various surveys on the Tibetan Plateau. In the 1980s, the international geoscience communites have launched dozens of international collaborative research programs on the Tibetan Plateau. Among them, there is the Sino-France Study on the Evolution and Dynamics of the Crust and the Upper Mantle of Hymalay, Sino-Japan Expedition to West Kunlun Mountain Glacier, Sino-Germany Tibetan Glacier Expedition, Sino-British Comprehensive Geological Investigation from Lhasa to Gomud, Sino-US Study on Thermo-balance in Tibetan Plateau, etc. Since the 1990s, more international research programs concerning the climate on the Tibetan Plateau have been launched, including: the Tibetan Ice Core Archives (TICA), Global Energy and Water cycle Experiment (GEWEX),) Asian Monsoon Experiment on the Tibetan Plateau (GAME/Tibet)[12], Coordinated Enhanced Observing Period (CEOP), Asia Australia Monsoon Project (CAMP)[13]. Entering the 21st century, the international collaborative programs become more comprehensive with the integration of interdisciplinary and multi-disciplinary research. The "Tibetan Plateau: Formation-Climate-Ecosystems" (TiP) is a long-running bilateral collaborative program between the Institute of Tibetan Plateau Research of the Chinese Academy of Science (ITP CAS) and DFG priority program 1372 (TiP). The collaboration has been evolved into a new program *TiPex* funded by BMBF in 2010 which plays a key role in the international initiative entitled "Third Pole Environment". Besides, the BRAHMATWINN program (2006–2010) funded by the European Commission under FP6 and the CEOP-AEGIS program (2008–2012) funded by the European Commission under FP7 (CEOP-AEGIS)[14] have also achieved great scientific progress. The "Third Pole Environment (TPE)" Program[15,16], which intends to promote the understanding of the interaction of the six spheres in the Tibetan Plateau and its surroundings, was initiated in 2009 by the international communities studying the Tibetan Plateau and its surroundings. It has gradually grown into an international platform that is conducive to addressing important scientific questions and coming up with adaptation policies to guide for human-nature harmany and social sustainability in the region.

Chinese Tibetan Plateau research has undergone step-wise progress. In the 1930s, Chinese scientists LIU Shen-e, XU jinzhi and SUN Jianchu investigated, respectively, the plants, geography and geology of Tibetan Plateau. Since the 1950s, Chinese scientists have carried out numerous comprehensive studies to address the needs of social and economic planning of the Tibetan Plateau. After 1990s, a number of projects have been supported by the National Basic Research Program of China (973 Program), including: Uplifting of Tibetan Plateau and Its Resource and Environmental Effects (1998), The Response of Environmental Changes on Tibetan Plateau to Global Changes and Adaptation Strategy (2005), Continental Collision and Related Metallogeny in Southern Tibetan Plateau (2010), Basic Research on the Major Permafrost Projects in the Qinghai-Tibet Plateau (2012), etc. Recently, the National Natural Science Foundation of China (NSFC) initiated a major program — "Multi-Phase Transformation of Water in the Earth System on the Third Pole and its Environmental Impacts", and the Chinese Academy of Sciences(CAS) launched Strategic Priority Research Program(B) — "Tibetan Plateau Multi-Spheres Interactions and its Resource and Environment Significance". By 2013, Chinese researchers produce the most publications of Tibetan Plateau-related papers in international journals, and the citation of those published papers also champions the number one in the international Tibetan Plateau research community[17]. Chinese scientists are planning on more international collaborations to promote earth system science research on the Tibetan Plateau.

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Extraterrestrial Life or Their Evidence Might be Found

1. Possibility of the existence of extraterrestrial life

Life is one of the most fascinating mysteries of nature. With the advances in space science and technology, life science has developed to the stage of exploring the possibility of existence of life outside the Earth system. In other words, by assessing the possibility of the existence of extraterrestrial life, its possible existence forms and regions can be determined roughly and the relevant theories and models can be also established. Combined with the development and application of the relevant detecting methods, it would be well-targeted to search for extraterrestrial life and various clues and evidences of its existence[1,2].

The belief in the existence of extraterrestrial life has supported by a simple fact — the existence of numerous terrestrial planets with Earth-like properties and the widespread existence of "super-Earth" in the universe. Consequently, the possibility of the existence of extraterrestrial life is increasingly accepted[3]. Till now, all of our understanding about extraterrestrial life is based on the knowledge of Earth life, thus the existence of liquid water and organics is regarded as the prerequisite for the existence of extraterrestrial life.

However, some scientists criticize such preconceived opinion for its possible impediment to the search for extraterrestrial life. Many lower forms of life are tenaciously surviving in an extremely harsh environment. Besides carbon-based life, extraterrestrial life may even exist in silicon-, ammonia-, and nitrogen-based forms[4].

2. Possible regions to find extraterrestrial life

(1) Planets and its nature satellites in the solar system that may sustain life

Mars: Current study of Mars has found the evidence of large quantities of underground water and other positive signs for the existence of life. Probes such as Odyssey, Phoenix, and Curiosity have discovered the existence of large quantities of water ice under Mars' surface. Growing evidence shows that Mars once had an active water system. Both Ground-based telescopes and Mars Express have detected methane in Mars' atmosphere. Whether or not the methane is produced by underground microbes of Mars is yet to be found out. At its landing site, the Probe Phoenix has found perchlorate, an important compound for microbial metabolism. Scientists deduce that the landing site may be suitable for life existence.

Europa: The observation data from the Galileo Spacecraft confirm that large quantities of relatively warm brine are embedded beneath the surface ice shell of Europa. Ice-water exchange makes it possible for energy and nutrients to be transferred between planet surface and water. Large quantities of hydrogen peroxide exist on the surface and in the ocean of Europa, which may probably be the energy source for simple life forms. New evidences also show that large shallow lakes exist under Europa's surface, which makes this satellite a likely candidate suitable for life existence.

Enceladus and Titan: Cassini spacecraft has detected a liquid-water ocean under the icy shell of Enceladus. Lakes and oceans with liquid hydrocarbon on Titan have ice on their surfaces, which makes chemical reaction at solid-liquid interface possible. Photochemical reaction of dicyanoacetylene at the bottom atmosphere and surface of Titan may finally produce building blocks of life.

(2) Outside the solar system. During nearly 20 years since the discovery of the first extrasolar planet, over 800 extrasolar planets and about 3,000 more candidates have been discovered. The common existence and diversity of extrasolar planets have become an indisputable fact.

Habitable zone is the area around the star where water can exist in liquid form. Planets in this zone are regarded as with greater chances to sustain life or have the environment supporting life existence[5]. So far, based on the observation results from Kepler and High Accuracy Radial Velocity Planet Searcher (HARPS), we have confirmed several planets in the habitable zone. Among them, Kepler-62e is regareded as the "most habitable planet ever discovered". Gliese 667C has at least six satellites and three of them, known as super-Earth, are in the habitable zone.

A series of advanced technologies including synthetic spectrum and induced phase amplitude apodization, can directly detect the "life marker" molecules in the atmosphere of extrasolar planets. In future, it is hopeful that the question of "whether or not a planet supports life" could be answered in a more rapid way[6].

3. International extraterrestrial life exploration programs are in full swing. Major discovery may be made in near future

Based on current detection capability, future search for extraterrestrial life or evidence of the existence of life will focus on three directions: searching life within the solar system; developing ground-based and space-based telescope to find out the environment supporting extraterrestrial life outside the solar system; and launching probes carrying earth information for extraterrestrial intelligence to find us.

(1) Extraterrestrial life search program within the solar system. Current efforts are mainly focused on Mars, Jupiter system, and Saturn system[7,8].

As far back as 1976, Viking spacecraft attempted to answer the question of whether or not life exists on Mars. Mars' atmosphere, soil, and rock samples have been researched by a series of following probes, including Mars Pathfinder, Mars Global Surveyor, Spirit, Opportunity, Mars Express, Phoenix, and Mars Science Laboratory and its rover Curiosity. Future missions, including ExoMars and Mars Sample Return, will continue attempts to search life on Mars.

In 1989, Galileo Spacecraft studied Europa. In 2012, ESA announced that JUpiter ICy moons Explorer (JUICE), the first large-scale mission of its Cosmic Vision program, would reveal whether or not Europa, Ganymede, and Callisto have potential habitable environment.

Space probes such as Pioneer 11, Voyager 1, Galileo, and Huygens all have observed Titan, which has highly similar geological features and atmosphere to that of primitive Earth and is highly possible to sustain life.

Recent studies prove that comets may bring water and even life to primitive Earth. Probes such as Deep Impact and Stardust have confirmed that comets contain basic substances for life and therefore may meet the primitive conditions for the origins of life.

(2) Space programs for extraterrestrial life outside the solar system.

Launched in 2006, COnvection ROtation and planetary Transits (CoRoT) is the first probe that is able to observe extrasolar terrestrial planets. Kepler spacecraft launched by NASA in 2009 is dedicated to searching exoplanets in our Milky Way Galaxy.

Future missions also include ESA's CHaracterizing ExOPlanet Satellite (CHEOPS), PLATO, and Exoplanet Characterization Observatory (EchO), and NASA's Space Interferometer and Astrobiology Laboratory. At present, China is building a high-performance observatory at Antarctic Dome A, at 4,087 meters above sea level. Upon its completion, the observatory will search for extraterrestrial life.

(3) Extraterrestrial intelligence exploration program.

Extraterrestrial intelligence may also try as hard as we do to search for external life. Based on this assumption, in addition to sending radio signals containing earth information to specific areas in the universe, NASA has also launched Pioneer and Voyager spacecrafts, hoping for being found by extraterrestrial intelligence. Search for Extraterrestrial Intelligence (SETI) program aims to find extraterrestrial intelligence by analyzing the regular electromagnetic signals received by radio telescopes[9].

Exploring extraterrestrial life will help us understand our "position" in the universe more profoundly. Several undergoing and to-be-implemented international space programs may find extraterrestrial life or evidence of existence of extraterrestrial life in near future. Such findings will be a major breakthrough in our understanding of nature and human beings. It will greatly expand our understanding of life phenomena and the law thereof, and will also certainly bring important inspiration for revealing the evolution mystery and future destination of all lives on Earth.

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Worldwide Space Programs Accelerate Breakthroughs in Fundamental Scientific Questions and Space Technologies

Outer space is the fourth territory for human beings in addition to the land, ocean and airspace. It was pointed out by Albert Einstein many years ago that science in the future might proceed in two different directions, i.e., towards either the microscopic world or the macroscopic world. These are exactly what space science is concerned with. On the cosmological scale, space science studies the universe. On the microscopic scale, space science studies the existence of dark matter, the basic laws of atoms and cells under extreme conditions and variable gravity in space. Therefore, space science is at the forefront of science in that it covers everything from the extremely large scale of the entire universe down to the extremely small scale of elementary particles. It is then a field that faces the most challenge, while also holding the promise to make great discoveries. During the first 10 years of the 21st century, a new round expansion of space exploration sprung up again. More and more countries put forward their long-and-medium-term space programs and continued to extend human presence into the deeper space. In 2012, the total budget of main space powers reached 72.9 billion US dollars (of which civil space accounted for 41.5 billion US dollars)[1], representing an increase of 44% over 2006 and doubling that of 2000. With worldwide space programs entering a new stage of active implementation by virtue of a high investment, space science researches, which take spacecrafts as the main platform of explorations, have kept on accelerating and changing our understanding of fundemental scientific questions with amazing achievements, and promoting the rapid development of related technologies.

1. ISS accomplishment will accelerate new scientific knowledge and relative benefits

With the main construction completed in 2011, International Space Station program (ISS) has entered the era of full utilization. The 29 internal research racks provide highly integrated research laboratories for human research, life science, fluid physics, combustion science, space material science, earth observation and so on, while the external trusses provide unique vantage points for the test payloads of astronomy, space physics and space technology. The multidisciplinary scientific research and utilization works undertaken in ISS have achieved many important results, and effectively promoted the development of innovative technologies and applications in space as well as on the ground. For example, the Alpha Magnetic Spectrometer (AMS-02) project team, chaired by Nobel Laureate Samuel Ting, has recently published its first research achievements, which proves that the ratio of positrons in the cosmic rays flow is beyond the theoretical expectation[2]. It is a possible new scientific discovery. It took 17 years to complete the construction of AMS-02 which was finally installed onto the ISS in 2011. The botanical experiment found that gravity was not the key factor to determine the growth model of plants[3]. A kind of spacecraft outer surface coating material tested in the serial materials experiments has been used in Juno, Gravity Recovery and Interior Laboratory (GRAIL) and Dragon spacecraft missions[4]. According to the statistics, from December 1998 to September 2012, the research results released by ISS program have been published in 588 journal articles and 159 conference papers. Some of the articles are published in *Nature, PANS, PRL* and other top journals[5], attracting great concerns from the whole world.

Currently, the major countries participating in ISS are more extensively arranging their scientific and applied research projects and developing higher-level scientific application payloads to be transported to ISS. The European Space Agency (ESA) is developing the containerless processing facility and the plasma physics research rack, and is planning to send Atomic Clock Ensemble in Space (ACES) to ISS in 2015. In addition, the development of a climate change monitoring platform and the Atmosphere-Space Interaction Monitor (ASIM) for atmospheric discharge detection is also on its deployment agenda. As for the Japan Aerospace Exploration Agency (JAXA), and the electrostatic levitation furnace experiment cabinet is nearing completion, Calorimeter Electronic Telescope (CALET) designed to detect the dark matter will be sent to ISS in 2013 as planned; besides, the plan of diffractive earth atmospheric Cherenkov detector to detect the ultra-high energy cosmic ray is underway. ISS is planned to operate at least until 2020, and it is expected to carry out thousands of scientific experiments and observations, space applications and technology experiments which will be the largest-scale space research activities in human history with great potential to obtain series of major research results.

2. Space science researches are increasingly abounding with great breakthroughs

In recent years, significant achievements in space science are emerging. For instance, the space scientific observations, including the successful detection of neutrinos and the discovery of cosmic X-ray sources, the blackbody form and anisotropy of cosmic microwave background radiation, and the accelerating expansion of the universe to reveal the existence of dark energy, have won Nobel Prize for Physics in 2002, 2006 and 2011; Wilkinson Microwave Anisotropy Probe (WMAP) found an irregular distribution occurring in the cosmic microwave background radiation pattern, which might be caused by the gravity exerted by other cosmoses, providing the first evidence for the controversial Multiverse theory[6]; although it is disputable that the "Voyager 1" has already flown out of the solar system, there is no doubt that the historic moment for artificial celestial bodies to fly across heliosphere boundary is being ushered[7]; the ancient river that once existed on Mars, a lot of liquid water existing beneath the surface of the ice on Europa and Enceladus, and other scientific concepts etc. have got convincing evidences; the number of newly-found exoplanets has been constantly refreshed.

In the five to ten years to come, human beings will conduct multi-band, full-time, high-resolution and high-precision solar observations. The unmanned aircraft will especially overcome the high temperature test to first implement a close observation of the sun and reveal the mechanism of solar activity. The chain change process research of solar activity – interplanetary distrubances – space storms of the earth – global change of the earth – human activity contains scientific discoveries and breakthroughs which will provide scientific support for the long-term sustainable development of mankind.

A large number of astronomical observations show that black holes with a quality several times as much as that of the sun pervade the galaxy and the super-massive black holes exist at the center of almost every galaxy. The black-hole research will produce major breakthroughs in the aspects of the formation and evolution of black holes, the space-time structure near the black hole and laws of physical movement, the tests of the general relativity theory, and so on. The dark matter and dark energy play a decisive role in the evolution history of the universe and determine its future and destiny, so research on them is likely to bring about series of scientific breakthroughs. The origin of Big Bang of the universe, the origin of various celestial bodies and structures in the universe and that of life itself are the important questions still puzzling human beings. The solution to address these scientific questions may bring forth a large number of scientific discoveries and even lead to a new revolution in physics.

Along with the continuous operations of Curiosity Rover, Juno Satellite and Aquarius Satellite, and successful launch of new missions, such as James Webb Space Telescope (JWST), Exobiology on Mars (ExoMars), Lisa Pathfinder, Solar Orbiter, Jupiter's Icy Moon Probe (JUICE) and so on, mankind will acquire more scientific knowledge of the formation and evolution of the universe, the tests of General Relativity, the nature of life, the sun's internal structure and dynamics as well as changes in the earth system, etc. As cosmology entering into the age of elaboration, a breakthrough in discovery of the dark matter in space is likely to be achieved; the theoretical validity of general relativity and quantum mechanics will be tested by experiments in space; the discovery of life or evidences of life outside the earth system will expand human understanding of phenomena and mysteries of life; the earth observation will play a crucial role in addressing "the most urgent problems of our planet" such as population, natural and man-made disasters and greenhouse gas emissions.

3. Both pulling and pushing effect of space science on space technology has been increasingly prominent while space technology will be further commercialized and market-oriented

With more ambitious scientific goals of the space programs worldwide, both the pull and push effects of space science on space technologies have become increasingly prominent, pulling out solar sail propulsion technology, ultrahigh precision spatial and time standards technology, etc. Many countries continue to strengthen the planning and investment in the areas of mission-driven key technologies and other pioneering and crosscutting technologies. NASA also emphasizes to maintain a balance between all the technology readiness levels and various technical fields[8]. Meanwhile, space technology will be further commercialized and market-oriented. U.S. Space-X's development has shown that commercial enterprises can also undertake the highly sophisticated tasks such as manned space flight even at a lower cost.

In short, our understanding of the origin and the matters of the universe is at a critical stage to witness major breakthroughs soon. The pilot deployment and successful implementation of the international space programs including the Chinese space station and the series of space science satellites will undoubtedly accelerate this process.

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Embracing the New Era of the Deep-sea Exploration

Oceans cover about 71% of the Earth's surface, have the huge capacities of storing and exchanging caloric, CO_2 and other active gases, and play an important role in regulating the global environment changes including climate change. Oceans contain rich resources, have special strategic position, and have attracted international attentions. As people are increasingly aware of the value of oceans, which are important for different countries to expand their interests, the marine science and technology has been the significant indicator of a country's comprehensive strength.

With the development of science and technology, the human is exploring the oceans from onshore to offshore and from shallow sea to deep sea. Nowadays, the deep-sea exploration, the deep earth exploration and the deep-space exploration ("Three Deep") have been the future important development direction of human science and technology in earth sciences, and have the possibility of achieving major breakthroughs.

1. Meaning and significance of the deep-sea exploration

The deep-sea exploration technology means collecting, analyzing and displaying the materials and data involving the deep-sea resources, components, phenomena and characteristics. It is the crucial technical means for preparatory work of deep-water development, which include deep-sea buoy technology, marine remote sensing technology, underwater acoustic detection techniques and deep-sea observation instrument technology. The deep-sea resources exploitation technologies associated to deep-sea resources exploration aim to develop the deep-sea resources and energies, including oil and gas resources development technology, mineral resources development technology, bio-resources development technology, the development of marine renewable energy technology. The deep-sea resources exploration and development of technologies have been the needs of countries and regions' long-term development strategy.

Since the 1960s, when developed countries took the first step to the deep-sea exploration, rapid technical progress has been made in the field, bringing about a variety of technologies, including Survey ships, drill ships/platforms, various types of detection instruments and equipment, unmanned/manned/remote submersibles, underwater robots, sampling equipment, subsea monitoring network, and constantly renewing detection breadth and depth. A series of major advances and new discoveries were made in the field of deep-sea extreme environments, earthquake mechanism, deep-sea biological and mineral resources, as well as the deep seabed material and structure[1].

With continuous innovation and development of marine survey detection technology, subsea exploration will gradually develop to deep-water, the oil and gas reserves in deep-sea will increase. The deep-sea biological gene resources have been the new type of resources which attracted international attentions in recent years; currently the deep-sea biological gene resources have brought billions of industrial value. Deep-sea marine creatures live in the unique physical, chemical and ecological environment, surrounded by high pressures, drastically changing temperature gradient, very slight light and high concentrations of toxic substances, then they have very unique biological structure and metabolism, various active substances in their bodies, like extreme enzymes, with a wide range of applications in the fields of medicine and environmental protection.

2. The new trends in the international deep-sea exploration

(1) The deep-sea exploration is rising up to a national strategic level. With rapid development of ocean exploration and exploitation technologies, considering the highly importance of resource reserves, exploring deep sea is rising up to a national strategic level. From the aspect of scientific research, the road from shallow to deep sea, from onshore to offshore, form sea surface to subsea, is the one that must follow when human beings observe, understand and exploit oceans. U.S. emphasis on the deep sea is particularly prominent, it made "*Global Ocean Science Plan*" as early as in 1986, stated that oceans were the last one would be exploited in Earth; in Dec 2004, America published "*U.S. Ocean Action Plan*", which became the guide of United States marine science and technology development in the 21 century, identified a priority to develop the deep-sea and high seas resources[2]. British and Japan added the deep-sea technology to the list of important breakthroughs as well, invested heavily in developing deep-sea exploration and resource development technologies, for instance, Japan's deep-sea drilling vessel *Chikyu* is in the international leading level; British published "UK marine science strategy" in Feb 2010, indicating the deep-sea technology to be a high level science priority[3].

(2) Mushrooming deep-sea scientific research programs worldwide. Apart from some international plans having a significant impact, such as "*Integrated Ocean Drilling Program(IODP, 2013–2023)*", "*InterRidge*" and "*InterMargins*", the plans or programs associated to Seafloor observatory network construction is growing intensively, such as America-NEPRUNE, *European Seafloor Observatory Network, Advanced Real-Time Earth Monitoring Network in the Area(ARENA), the New Jersy Shelf Observing System NJSOS*[4]. The characteristics of these deep-sea research and observation plans are: main sponsors are the countries take a leading in deep-sea research, such as America, Japan and part of European countries; with development of technology, the plans involving subsea observing network is growing gradually, reflecting the overall progress of the deep-sea technology; the specialized observation station construction for hot areas of deep-sea research (e.g. hydrothermal) is becoming popular.

(3) Deep-sea exploration technology is crucial to significant breakthroughs of future science and technology. The development of ocean observation technology, especially deep-sea observation technology, such as riser and non-riser technology mentioned by IODP, subsea continuous observation technology mentioned by *InterRidge*, has been crucial to promote significant scientific breakthrough[5,6]. In May 31, 2009, U.S. "Poseidon" submarine dived to the deepest of the world's oceans-the Challenger Deep of Mariana Trench in the western Pacific, approximately 10 902m, marking the major breakthrough of the deep-sea exploration. With the increasing progress of these deep diving devices' exploration depth and observing performance, the human being's abilities of understanding deep sea is continuously upgrading as well, which will promote the human beings' understanding and awareness of unknown oceans.

(4) Deep-sea exploration technology becomes to be the comprehensive technology field integrating various high-techs. The current deep-sea technology is a complicated high-tech system which integrates all areas of science and technology. From the application point of view, it can be classified into: deep-sea exploration/observation technology, deep-sea sampling technology, deep-sea exploration and development technology, deep-sea space utilization technology, deep-sea environmental protection technology and deep-sea equipment technology. Regarding to the technology, it involves many disciplines and technical fields, such as microelectronics, information technology, remote sensing technology, acoustic technology, visualization technology and computer network technology as well as materials and energy, it can be said that deep-sea technology is the applications and development of the current various universal technologies and the latest technologies in the deep sea of special environment.

(5) Closer international cooperation in deep-sea exploration. The cooperation between countries, regions, scientific research institutions and enterprises is becoming the trend of future international cooperation. Bibliometric analysis suggest that America, Japan and Europe form a core cooperative group in the field of deep-sea science and technology. America, British, France, German and Japan accelerate the development of deep-sea technology by government support, alliances between the scientific community and the business community, international cooperation, generally are in the leading position in the field of deep-sea technology.

3. China's advantages in the field of deep-sea exploration technology

China will designate a region of cobalt-rich crusts in the seabed to meet the resource requirements of its business development, while investigating seafloor hydrothermal sulfides and other resources. At the same time, China is launching a comprehensive deep-sea biological gene research. China will positively develop the key technologies of submarine detection and the exploration and evaluation of ocean resources, break through the technologies of deep-sea operation, subsea multi-parameter detection, in situ detection of deep seabed, deep-sea workstation, minerals and bio-genetic video sampling, finally form a system of deep-sea exploration and sampling.

(1) Deepwater oil and gas exploration. China has owned the first Deepwater semi-submersible drilling platform "COSLPIONEER", operating depth of 750 m, the drilling depth of 7500 m, the drilling equipment has the function of automatic drilling. In 2010, CNOOC built 3000 m deep-water semi-submersible drilling platform "Offshore Oil 981", with the most operating depth of 3050 m, and drilling depth of 10,000 m, almost it is able to work in all of global deep water areas, recently it launched a first exploration of deep-water oil and gas in South China Sea independently. China has developed a series of deep-sea oil and gas and seismic exploration technologies independently, which consist of the technology of hypocenter seismic exploration in a single vessel with long cables and high capacities and the corresponding supporting technologies, the technology of OBS ocean bottom seismic exploration[7,8]. A National High-tech R&D Program (863 Program), "key technologies for gas hydrate exploration and development", has made a number of innovative achievements with independent intellectual property rights[9].

(2) Scientific investigation into oceans. Currently, China has integrated marine scientific survey ships, "Ocean No.1" and "Ocean No.6", a polar research vessel "Chinare" and a new integrated marine scientific survey ship "Science" built by institution of oceanology of CAS; these ships are equipped with various advanced detection apparatus, equipment and installations. Since the 1990s, China started the integrated scientific survey in deep sea, Antarctic and Arctic polar, began the study on marine minerals, deep-sea biological-gene resources.

The newly-built ship "Science" is equipped with international advanced exploration and investigation devices and modern labs. It can meet the needs of modern deep-sea and ocean exploration; and provide the integrated offshore platform to deep-sea exploration and research. The Deep Sea Research Center is planning to response to the status quo of deep-sea research. This center will focus on cutting-edge hot issues on deep-sea science, gather the advantage institutions referring to ocean research, construct the institution with international competitiveness for the targets of deep-sea science and resource exploration and development, finally become to be the crucial technical forces supporting deep-sea resource exploration and development and deep sea scientific research.

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