Chinese Academy of Sciences

Yong Chen
Editor

Energy Science & Technology in China: A Roadmap to 2050

Science Press
Beijing

Springer

Yong Chen

Energy Science & Technology in China: A Roadmap to 2050

Chinese Academy of Sciences

Yong Chen
Editor

Energy Science & Technology in China: A Roadmap to 2050

With 25 Figures

Science Press
Beijing

Springer

Editor
Yong Chen
Guangzhou Branch, CAS
510070, Guangzhou, China
E-mail: Chenyong@ms.giec.ac.cn

ISBN 978-7-03-025652-2
Science Press Beijing

ISBN 978-3-642-05319-1 e-ISBN 978-3-642-05320-7
Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2009937357

Cover design: Frido Steinen-Broo, EStudio Calamar, Spain

Printed on acid-free paper

Springer is a part of Springer Science+Business Media (www.springer.com)

Members of the Editorial Committee and the Editorial Office

Editor-in-Chief

Yongxiang Lu

Editorial Committee

Yongxiang Lu Chunli Bai Erwei Shi Xin Fang Zhigang Li Xiaoye Cao Jiaofeng Pan

Research Group on Energy of the Chinese Academy of Sciences

Group Head: Yong Chen

Deputy Head: Chuangzhi Wu

General Consultant: Luguang Yan

Group of Consultant: Luguang Yan Shouxian Fang Jiyang Wang

Group Members (In the alphabetical order of Chinese surname):

Xinhe Bao	Dalian Institute of Chemical Physics, CAS
Guotian Cai	Guangzhou Institute of Energy Conversion, CAS
Yong Chen	Guangzhou Branch, CAS
Shaotao Dai	Institute of Electrical Engineering, CAS
Songyuan Dai	Institute of Plasma Physics, CAS
Shouxian Fang	Institute of High Energy Physics, CAS
Yulie Gong	Guangzhou Institute of Energy Conversion, CAS
Guobiao Gu	Institute of Electrical Engineering, CAS
Li Han	Institute of Electrical Engineering, CAS
Yizhuo Han	Institute of Coal Chemistry, CAS
Ningsheng Huang	Guangzhou Branch, CAS
Weiguang Huang	Institute of Engineering Thermophysics, CAS
Lucheng Ji	Bureau of Hi-Tech Research and Development, CAS
Fantai Kong	Institute of Plasma Physics, CAS
Jiangang Li	Institute of Plasma Physics, CAS
Jianglin Li	Institute of Electrical Engineering, CAS
Xiaosen Li	Guangzhou Institute of Energy Conversion, CAS
Yaohua Li	Institute of Electrical Engineering, CAS
Longlong Ma	Guangzhou Institute of Energy Conversion, CAS
Weibin Ma	Guangzhou Institute of Energy Conversion, CAS
Zhonghe Pang	Institute of Geology and Geophysics, CAS
Zhiping Qi	Institute of Electrical Engineering, CAS
Yongming Sun	Guangzhou Institute of Energy Conversion, CAS
Jianzhong Tong	Institute of Electrical Engineering, CAS
Baonian Wan	Institute of Plasma Physics, CAS
Jiyang Wang	Institute of Geology and Geophysics, CAS

Shudong Wang	Dalian Institute of Chemical Physics, CAS
Zhifeng Wang	Institute of Electrical Engineering, CAS
Rong Wei	Institute of Electrical Engineering, CAS
Xuhui Wen	Institute of Electrical Engineering, CAS
Chuangzhi Wu	Guangzhou Institute of Energy Conversion, CAS
Liye Xiao	Institute of Electrical Engineering, CAS
Zhijian Xiong	Institute of Coal Chemistry, CAS
Honghua Xu	Institute of Electrical Engineering, CAS
Luguang Yan	Institute of Electrical Engineering, CAS
Yage You	Guangzhou Institute of Energy Conversion, CAS
Zhenhong Yuan	Guangzhou Institute of Energy Conversion, CAS
Zhongshan Yuan	Dalian Institute of Chemical Physics, CAS
Jun Zhang	The Wuhan Branch of the National Science Library, CAS
Meimei Zhang	Institute of Electrical Engineering, CAS
Daiqing Zhao	Guangzhou Institute of Energy Conversion, CAS

Foreword to the Roadmaps 2050*

China's modernization is viewed as a transformative revolution in the human history of modernization. As such, the Chinese Academy of Sciences (CAS) decided to give higher priority to the research on the science and technology (S&T) roadmap for priority areas in China's modernization process. What is the purpose? And why is it? Is it a must? I think those are substantial and significant questions to start things forward.

Significance of the Research on China's S&T Roadmap to 2050

We are aware that the National Mid- and Long-term S&T Plan to 2020 has already been formed after two years' hard work by a panel of over 2000 experts and scholars brought together from all over China, chaired by Premier Wen Jiabao. This clearly shows that China has already had its S&T blueprint to 2020. Then, why did CAS conduct this research on China's S&T roadmap to 2050?

In the summer of 2007 when CAS was working out its future strategic priorities for S&T development, it realized that some issues, such as energy, must be addressed with a long-term view. As a matter of fact, some strategic researches have been conducted, over the last 15 years, on energy, but mainly on how to best use of coal, how to best exploit both domestic and international oil and gas resources, and how to develop nuclear energy in a discreet way. Renewable energy was, of course, included but only as a supplementary energy. It was not yet thought as a supporting leg for future energy development. However, greenhouse gas emissions are becoming a major world concern over

* It is adapted from a speech by President Yongxiang Lu at the first High-level Workshop on China's S&T Roadmap for Priority Areas to 2050, organized by the Chinese Academy of Sciences, in October, 2007.

the years, and how to address the global climate change has been on the agenda. In fact, what is really behind is the concern for energy structure, which makes us realize that fossil energy must be used cleanly and efficiently in order to reduce its impact on the environment. However, fossil energy is, pessimistically speaking, expected to be used up within about 100 years, or optimistically speaking, within about 200 years. Oil and gas resources may be among the first to be exhausted, and then coal resources follow. When this happens, human beings will have to refer to renewable energy as its major energy, while nuclear energy as a supplementary one. Under this situation, governments of the world are taking preparatory efforts in this regard, with Europe taking the lead and the USA shifting to take a more positive attitude, as evidenced in that: while fossil energy has been taken the best use of, renewable energy has been greatly developed, and the R&D of advanced nuclear energy has been reinforced with the objective of being eventually transformed into renewable energy. The process may last 50 to 100 years or so. Hence, many S&T problems may come around. In the field of basic research, for example, research will be conducted by physicists, chemists and biologists on the new generation of photovoltaic cell, dye-sensitized solar cells (DSC), high-efficient photochemical catalysis and storage, and efficient photosynthetic species, or high-efficient photosynthetic species produced by gene engineering which are free from land and water demands compared with food and oil crops, and can be grown on hillside, saline lands and semi-arid places, producing the energy that fits humanity. In the meantime, although the existing energy system is comparatively stable, future energy structure is likely to change into an unstable system. Presumably, dispersive energy system as well as higher-efficient direct current transmission and storage technology will be developed, so will be the safe and reliable control of network, and the capture, storage, transfer and use of CO_2, all of which involve S&T problems in almost all scientific disciplines. Therefore, it is natural that energy problems may bring out both basic and applied research, and may eventually lead to comprehensive structural changes. And this may last for 50 to 100 years or so. Taking the nuclear energy as an example, it usually takes about 20 years or more from its initial plan to key technology breakthroughs, so does the subsequent massive application and commercialization. If we lose the opportunity to make foresighted arrangements, we will be lagging far behind in the future. France has already worked out the roadmap to 2040 and 2050 respectively for the development of the 3rd and 4th generation of nuclear fission reactors, while China has not yet taken any serious actions. Under this circumstance, it is now time for CAS to take the issue seriously, for the sake of national interests, and to start conducting a foresighted research in this regard.

This strategic research covers over some dozens of areas with a long-term view. Taking agriculture as an example, our concern used to be limited only to the increased production of high-quality food grains and agricultural by-products. However, in the future, the main concern will definitely be given to the water-saving and ecological agriculture. As China is vast in territory, diversified technologies in this regard are the appropriate solutions. Animal husbandry has been used by developed countries, such as Japan and Denmark, to make bioreactor and pesticide as well. Plants have been used by Japan to make bioreactors which are safer and cost-effective than that made from animals. Potato, strawberry, tomato and the like have been bred in germ-free greenhouses, and value-added products have been made through gene transplantation technology. Agriculture in China must not only address the food demands from its one billions-plus population, but also take into consideration of the value-added agriculture by-products and the high-tech development of agriculture as well. Agriculture in the future is expected to bring out some energies and fuels needed by both industry and man's livelihood as well. Some developed countries have taken an earlier start to conduct foresighted research in this regard, while we have not yet taken sufficient consideration.

Population is another problem. It will be most likely that China's population will not drop to about 1 billion until the end of this century, given that the past mistakes of China's population policy be rectified. But the subsequent problem of ageing could only be sorted out until the next century. The current population and health policies face many challenges, such as, how to ensure that the 1.3 to 1.5 billion people enjoy fair and basic public healthcare; the necessity to develop advanced and public healthcare and treatment technologies; and the change of research priority to chronic diseases from infectious diseases, as developed countries have already started research in this regard under the increasing social and environmental change. There are many such research problems yet to be sorted out by starting from the basic research, and subsequent policies within the next 50 years are in need to be worked out.

Space and oceans provide humanity with important resources for future development. In terms of space research, the well-known Manned Spacecraft Program and China's Lunar Exploration Program will last for 20 or 25 years. But what will be the whole plan for China's space technology? What is the objective? Will it just follow the suit of developed countries? It is worth doing serious study in this regard. The present spacecraft is mainly sent into space with chemical fuel propellant rocket. Will this traditional propellant still be used in future deep space exploration? Or other new technologies such as electrical propellant, nuclear energy propellant, and solar sail technologies be developed? We haven't yet done any strategic research over these issues, not even worked out any plans. The ocean is abundant in mineral resources, oil and gas, natural gas hydrate, biological resources, energy and photo-free biological evolution, which may arise our scientific interests. At present, many countries have worked out new strategic marine plans. Russia, Canada, the USA, Sweden and Norway have centered their contention upon the North Pole, an area of strategic significance. For this, however, we have only limited plans.

The national and public security develops with time, and covers both conventional and non-conventional security. Conventional security threats only refer to foreign invasion and warfare, while, the present security threat may come out from any of the natural, man-made, external, interior, ecological, environmental, and the emerging networking (including both real and virtual) factors. The conflicts out of these must be analyzed from the perspective of human civilization, and be sorted out in a scientific manner. Efforts must be made to root out the cause of the threats, while human life must be treasured at any time.

In general, it is necessary to conduct this strategic research in view of the future development of China and mankind as well. The past 250 years' industrialization has resulted in the modernization and better-off life of less than 1 billion people, predominantly in Europe, North America, Japan and Singapore. The next 50 years' modernization drive will definitely lead to a better-off life for 2–3 billion people, including over 1 billion Chinese, doubling or tripling the economic increase over that of the past 250 years, which will, on the one hand, bring vigor and vitality to the world, and, on the other hand, inevitably challenge the limited resources and eco-environment on the earth. New development mode must be shaped so that everyone on the earth will be able to enjoy fairly the achievements of modern civilization. Achieving this requires us, in the process of China's modernization, to have a foresighted overview on the future development of world science and human civilization, and on how science and technology could serve the modernization drive. S&T roadmap for priority areas to 2050 must be worked out, and solutions to core science problems and key technology problems must be straightened out, which will eventually provide consultations for the nation's S&T decision-making.

Possibility of Working out China's S&T Roadmap to 2050

Some people held the view that science is hard to be predicted as it happens unexpectedly and mainly comes out of scientists' innovative thinking, while, technology might be predicted but at the maximum of 15 years. In my view, however, S&T foresight in some areas seems feasible. For instance, with the exhaustion of fossil energy, some smart people may think of transforming solar energy into energy-intensive biomass through improved high-efficient solar thin-film materials and devices, or even developing new substitute. As is driven by huge demands, many investments will go to this emerging area. It is, therefore, able to predict that, in the next 50 years, some breakthroughs will undoubtedly be made in the areas of renewable energy and nuclear energy as well. In terms of solar energy, for example, the improvement of photoelectric conversion efficiency and photothermal conversion efficiency will be the focus. Of course, the concrete technological solutions may be varied, for example, by changing the morphology of the surface of solar cells and through the reflection, the entire spectrum can be absorbed more efficiently; by developing multi-layer functional thin-films for transmission and absorption; or by introducing of nanotechnology and quantum control technology, etc. Quantum control research used to limit mainly to the solution to information functional materials. This is surely too narrow. In the future, this research is expected to be extended to the energy issue or energy-based basic research in cutting-edge areas.

In terms of computing science, we must be confident to forecast its future development instead of simply following suit as we used to. This is a possibility rather than wild fancies. Information scientists, physicists and biologists could be engaged in the forward-looking research. In 2007, the Nobel Physics Prize was awarded to the discovery of colossal magneto-resistance, which was, however, made some 20 years ago. Today, this technology has already been applied to hard disk store. Our conclusion made, at this stage, is that: it is possible to make long-term and unconventional S&T predictions, and so is it to work out China's S&T roadmap in view of long-term strategies, for example, by 2020 as the first step, by 2030 or 2035 as the second step, and by 2050 as the maximum.

This possibility may also apply to other areas of research. The point is to emancipate the mind and respect objective laws rather than indulging in wild fancies. We attribute our success today to the guidelines of emancipating the mind and seeking the truth from the facts set by the Third Plenary Session of the 11th Central Committee of the Communist Party of China in 1979. We must break the conventional barriers and find a way of development fitting into China's reality. The history of science tells us that discoveries and breakthroughs could only be made when you open up your mind, break the conventional barriers, and make foresighted plans. Top-down guidance on research with increased financial support and involvement of a wider range of talented scientists is not in conflict with demand-driven research and free discovery of science as well.

Necessity of CAS Research on China's S&T Roadmap to 2050

Why does CAS launch this research? As is known, CAS is the nation's highest academic institution in natural sciences. It targets at making basic, forward-looking and strategic research and playing a leading role in China's science. As such, how can it achieve this if without a foresighted view on science and technology? From the perspective of CAS, it is obligatory to think, with a global view, about what to do after the 3rd Phase of the Knowledge Innovation Program (KIP). Shall we follow the way as it used to? Or shall we, with a view of national interests, present our in-depth insights into different research disciplines, and make efforts to reform the organizational structure and system, so that the innovation capability of CAS and the nation's science and technology mission will be raised to a new height? Clearly, the latter is more positive. World science and technology develops at a lightening speed. As global economy grows, we are aware that we will be lagging far behind if without making progress, and will lose the opportunity if without making foresighted plans. S&T innovation requires us to make joint efforts, break the conventional barriers and emancipate the mind. This is also what we need for further development.

The roadmap must be targeted at the national level so that the strategic research reports will form an important part of the national long-term program. CAS may not be able to fulfill all the objectives in the reports. However, it can select what is able to do and make foresighted plans, which will eventually help shape the post-2010 research priorities of CAS and the guidelines for its future reform.

Once the long-term roadmap and its objectives are identified, system mechanism, human resources, funding and allocation should be ensured for full implementation. We will make further studies to figure out: What will happen to world innovation system within the next 30 to 50 years? Will universities, research institutions and enterprises still be included in the system? Will research institutes become grid structure? When the cutting-edge research combines basic science and high-tech and the transformative research integrates the cutting-edge research with industrialization, will that be the research trend in some disciplines? What will be the changes for personnel structure, motivation mechanism and upgrading mechanism within the innovation system? Will there be any changes for the input and structure of innovation resources? If we could have a clear mind of all the questions, make foresighted plans and then dare to try out in relevant CAS institutes, we will be able to pave a way for a more competitive and smooth development.

Social changes are without limit, so are the development of science and technology, and innovation system and management as well. CAS must keep moving ahead to make foresighted plans not only for science and technology, but also for its organizational structure, human resources, management modes, and resource structures. By doing so, CAS will keep standing at the forefront of science and playing a leading role in the national innovation system, and even, frankly speaking, taking the lead in some research disciplines in the world. This is, in fact, our purpose of conducting the strategic research on China's S&T roadmap.

Prof. Dr.-Ing. Yongxiang Lu

President of the Chinese Academy of Sciences

Preface to the Roadmaps 2050

CAS is the nation's think tank for science. Its major responsibility is to provide S&T consultations for the nation's decision-makings and to take the lead in the nation's S&T development.

In July, 2007, President Yongxiang Lu made the following remarks: "In order to carry out the Scientific Outlook of Development through innovation, further strategic research should be done to lay out a S&T roadmap for the next 20–30 years and key S&T innovation disciplines. And relevant workshops should be organized with the participation of scientists both within CAS and outside to further discuss the research priorities and objectives. We should no longer confine ourselves to the free discovery of science, the quantity and quality of scientific papers, nor should we satisfy ourselves simply with the Principal Investigators system of research. Research should be conducted to address the needs of both the nation and society, in particular, the continued growth of economy and national competitiveness, the development of social harmony, and the sustainability between man and nature."

According to the Executive Management Committee of CAS in July, 2007, CAS strategic research on S&T roadmap for future development should be conducted to orchestrate the needs of both the nation and society, and target at the three objectives: the growth of economy and national competitiveness, the development of social harmony, and the sustainability between man and nature.

In August, 2007, President Yongxiang Lu further put it: "Strategic research requires a forward-looking view over the world, China, and science & technology in 2050. Firstly, in terms of the world in 2050, we should be able to study the perspectives of economy, society, national security, eco-environment, and science & technology, specifically in such scientific disciplines as energy, resources, population, health, information, security, eco-environment, space and oceans. And we should be aware of where the opportunities and challenges lie. Secondly, in terms of China's economy and society in 2050, we should take into consideration of factors like: objectives, methods, and scientific supports needed for economic structure, social development, energy structure, population and health, eco-environment, national security and innovation capability. Thirdly, in terms of the guidance of Scientific Outlook of Development on science and technology, it emphasizes the people's interests and development, science and technology, science and economy, science and society, science and eco-environment, science and culture, innovation and collaborative development. Fourthly, in terms of the supporting role of research in scientific development, this includes how to optimize the economic structure and boost economy, agricultural development, energy structure, resource conservation, recycling economy, knowledge-based society, harmonious coexistence between man and nature, balance of regional development, social harmony, national security, and international cooperation. Based on these, the role of CAS will be further identified."

Subsequently, CAS launched its strategic research on the roadmap for priority areas to 2050, which comes into eighteen categories including: energy, water resources, mineral resources, marine resources, oil and gas, population and health, agriculture, eco-environment, biomass resources, regional development, space, information, advanced manufacturing, advanced materials, nano-science, big science facilities, cross-disciplinary and frontier research, and national and public security. Over 300 CAS experts in science, technology, management and documentation & information, including about 60 CAS members, from over 80 CAS institutes joined this research.

Over one year's hard work, substantial progress has been made in each research group of the scientific disciplines. The strategic demands on priority areas in China's modernization drive to 2050 have been strengthened out; some core science problems and key technology problems been set forth; a relevant S&T roadmap been worked out based on China's reality; and eventually the strategic reports on China's S&T roadmap for eighteen priority areas to 2050 been formed. Under the circumstance, both the Editorial Committee and Writing Group, chaired by President Yongxiang Lu, have finalized the general report. The research reports are to be published in the form of CAS strategic research serial reports, entitled *Science and Technology Roadmap to China 2050: Strategic Reports of the Chinese Academy of Sciences*.

The unique feature of this strategic research is its use of S&T roadmap approach. S&T roadmap differs from the commonly used planning and technology foresight in that it includes science and technology needed for the future, the roadmap to reach the objectives, description of environmental changes, research needs, technology trends, and innovation and technology development. Scientific planning in the form of roadmap will have a clearer scientific objective, form closer links with the market, projects selected be more interactive and systematic, the solutions to the objective be defined, and the plan be more feasible. In addition, by drawing from both the foreign experience on roadmap research and domestic experience on strategic planning, we have formed our own ways of making S&T roadmap in priority areas as follows:

(1) Establishment of organization mechanism for strategic research on S&T roadmap for priority areas

The Editorial Committee is set up with the head of President Yongxiang Lu and the involvement of Chunli Bai, Erwei Shi, Xin Fang, Zhigang Li, Xiaoye Cao and Jiaofeng Pan. And the Writing Group was organized to take responsibility of the research and writing of the general report. CAS Bureau of Planning and Strategy, as the executive unit, coordinates the research, selects the scholars, identifies concrete steps and task requirements, sets forth research approaches, and organizes workshops and independent peer reviews of the research, in order to ensure the smooth progress of the strategic research on the S&T roadmap for priority areas.

(2) Setting up principles for the S&T roadmap for priority areas

The framework of roadmap research should be targeted at the national level, and divided into three steps as immediate-term (by 2020), mid-term (by 2030) and long-term (by 2050). It should cover the description of job requirements, objectives, specific tasks, research approaches, and highlight core science problems and key technology problems, which must be, in general, directional, strategic and feasible.

(3) Selection of expertise for strategic research on the S&T roadmap

Scholars in science policy, management, information and documentation, and chief scientists of the middle-aged and the young should be selected to form a special research group. The head of the group should be an outstanding scientist with a strategic vision, strong sense of responsibility and coordinative capability. In order to steer the research direction, chief scientists should be selected as the core members of the group to ensure that the strategic research in priority areas be based on the cutting-edge and frontier research. Information and documentation scholars should be engaged in each research group to guarantee the efficiency and systematization of the research through data collection and analysis. Science policy scholars should focus on the strategic demands and their feasibility.

(4) Organization of regular workshops at different levels

Workshops should be held as a leverage to identify concrete research steps and ensure its smooth progress. Five workshops have been organized consecutively in the following forms:

High-level Workshop on S&T Strategies. Three workshops on S&T strategies have been organized in October, 2007, December, 2007, and June, 2008, respectively, with the participation of research group heads in eighteen priority areas, chief scholars, and relevant top CAS management members. Information has been exchanged, and consensus been reached to ensure research directions. During the workshops, President Yongxiang Lu pinpointed the significance, necessity and possibility of the roadmap research, and commented on the work of each research groups, thus pushing the research forward.

Special workshops. The Editorial Committee invited science policy scholars to the special workshops to discuss the eight basic and strategic systems for China's socio-economic development. Perspectives on China's science-driven modernization to 2050 and characteristics and objectives of the eight systems have been outlined, and twenty-two strategic S&T problems affecting the modernization have been figured out.

Research group workshops. Each research group was further divided into different research teams based on different disciplines. Group discussions, team discussions and cross-team discussions were organized for further research, occasionally with the involvement of related scholars in special topic discussions. Research group workshops have been held some 70 times.

Cross-group workshops. Cross-group and cross-disciplinary workshops were organized, with the initiation by relative research groups and coordination by Bureau of Planning and Strategies, to coordinate the research in relative disciplines.

Professional workshops. These workshops were held to have the suggestions and advices of both domestic and international professionals over the development and strategies in related disciplines.

(5) Establishment of a peer review mechanism for the roadmap research

To ensure the quality of research reports and enhance coordination among different disciplines, a workshop on the peer review of strategic research on the S&T roadmap was organized by CAS Bureau of Planning and Strategy, in November, 2008, bringing together of about 30 peer review experts and 50 research group scholars. The review was made in four different categories, namely, resources and environment, strategic high-technology, bio-science & technology, and basic research. Experts listened to the reports of different research groups, commented on the general structure, what's new and existing problems, and presented their suggestions and advices. The outcomes were put in the written forms and returned to the research groups for further revisions.

(6) Establishment of a sustained mechanism for the roadmap research

To cope with the rapid change of world science and technology and national demands, a roadmap is, by nature, in need of sustained study, and should be revised once in every 3–5 years. Therefore, a panel of science policy scholars should be formed to keep a constant watch on the priority areas and key S&T problems for the nation's long-term benefits and make further study in this regard. And hopefully, more science policy scholars will be trained out of the research process.

The serial reports by CAS have their contents firmly based on China's reality while keeping the future in view. The work is a crystallization of the scholars' wisdom, written in a careful and scrupulous manner. Herewith, our sincere gratitude goes to all the scholars engaged in the research, consultation and review. It is their joint efforts and hard work that help to enable the serial reports to be published for the public within only one year.

To precisely predict the future is extremely challenging. This strategic research covered a wide range of areas and time, and adopted new research approaches. As such, the serial reports may have its deficiency due to the limit in knowledge and assessment. We, therefore, welcome timely advice and enlightening remarks from a much wider circle of scholars around the world.

The publication of the serial reports is a new start instead of the end of the strategic research. With this, we will further our research in this regard, duly release the research results, and have the roadmap revised every five years, in an effort to provide consultations to the state decision-makers in science, and give suggestions to science policy departments, research institutions, enterprises, and universities for their S&T policy-making. Raising the public awareness of science and technology is of great significance for China's modernization.

Writing Group of the General Report

February, 2009

Preface

Being the public resource for the survival of human beings and the development of society, energy is the material guarantee for national and regional economic development. Energy is not only economic resource, but strategic and political resource as well. The storage and sustainable development of energy technology directly influence our nation's security and modernization. Throughout the history of human society, every significant progress of human civilization came with the substitute of energy types and advancement of energy technology. With the industrial revolution in the 18th century, the invention of steam engine and the application of electricity spurred the utilization of coal. Since then, coal took the place of firewood and became the main energy source for human beings. After mid-19th century, the use of petroleum and natural gas as energy sources began respectively in the year of 1870 and 1880. The rapid development of car, airplane, vessel and other heavy industries pushed forward the advancement of industry and reform of society. From the mid-20th century till now, the total consumption share of petroleum and natural gas keep increasing. They have been the mainstream primary energy sources globally, together with coal. Since mid-20th century, the development and utilization of nuclear energy transformed energy structure and urged technology improvement. Moreover, nuclear energy is regarded as important political bargaining chips.

In the past century, developed countries finished industrialization which accelerated the huge consumption of fossil energy. At present, many developing countries are heading for the process of industrialization which further enlarges the total consumption. The shortage of fossil energy sources has become a severe constraint for our global economic development. Meanwhile, owing to the prolonged combustion of tremendous amount of fossil fuel, greenhouse gases are emitted and accumulated in the atmosphere. This gives rise to the greenhouse effect, which leads to the significant increase in the frequency of natural disasters and extreme climate conditions and threatens the sustainable development of human society, and hence challenges the energy structure with fossil fuel as its core. In such a condition, after we entered the 21st century, human beings appealed to the development of new and renewable energy and establishment of efficient, economical, clean and sustainable energy supply system, which will push forward the revolution of technology and advancement of civilization and society.

To establish an efficient, economical, clean and sustainable energy supply system which meets the demand of a low-carbon economy, solving the tremendous numbers of science and technology problems is the first priority. For instance, in the field of solar power, we need to solve the problems of efficient and low-cost photoelectric conversion materials, solar thermal power generation technology and heat transfer media. In the field of biomass, we need to solve the problems of the selection and cultivation of energy plants and oil-containing micro algae, their directional conversion and synthesis, preparation of low-cost, high-efficiency catalysts and transmission and cellulose conversion. In the field of clean and high-added-value utilization of coal, we need to solve the problems of adjustable technology of hydrocarbon, catalytic combustion and reaction control of new clean coal combustion technology, product directional transfer control in the coal chemical conversion process, design in composite application of coal and renewable energy as well as their process integration technology and carbon dioxide capture and storage. In the field of nuclear energy, we need to solve the problems of new nuclear power technology, accelerator driven system and nuclear fusion technology. In the field of natural gas hydrates development and utilization, we need to solve the problems of investigation and assessment of resources, exploiting technology, security and environmental influence.

Energy has the characteristics of large-investment, multi-link, long-cycle and strong-inertia, once the direction is wrong or the technology lag behind, the passive situation of being constrained by foreign technology will occur in the following decades. It was proved that the insufficiency of fundamental, perspective and strategic deployment in China led to our dependence on imports for the core energy technology and advanced equipment. This directly influenced our national energy security. Therefore, to ensure the sustainable development of our economy and society as well as our modernization, we should establish an innovative energy system that suits China's development demand and characteristics, seize the opportunities of the alteration from fossil fuel to new and renewable energy, narrow the gap between our technology and the foreign advanced technology, enter the front rank of global energy technology, and hence support the development of Chinese sustainable energy system as well as the formation of Chinese energy technology innovation system.

According to the unified deployment by the Chinese Academy of Sciences, we established the energy strategy research group of CAS which was composed of more than 30 experts. From the embodiment of strategic direction and a certain degree of feasibility requirements, we draw the roadmap for future development based on that of the developed countries. We took three different periods of development, 2008—2020, 2021—2035 and 2036—2050 respectively, as the time nodes, and set up *Energy Science & Technology in China: A Roadmap to 2050* with the logical pattern of "demand of energy development→important energy technology issues→important energy technology direction→technology development roadmap→general deployment for energy technology innovation→guarantee for system construction".

During the process of research and establishment, the energy strategy research group has thoroughly implemented the principle of "autonomous innovation, giving prominence to stride over, supporting development and leading the future" to solve our economic and social development energy bottleneck constraint first. They strived to open their mind, make bold explorations, independently innovate and exploit, put forward new ideas, explore new science and technology, infer the key core R&D technology model application, promote advanced energy technology into productivity, support the modernization of energy systems for sustainable development, and make basic, strategic, perspective contributions on the whole.

For the important energy technology direction and the choice of roadmap, they followed five fundamental principles: ① independent R&D technologies that can no longer meet current need, are to be digested and absorbed; ② technologies with promising future yet only applied in a small scale are to be focused on, researched and to strive for a breakthrough; ③ technologies with demanded significantly in the future but are still under research and discovery are to be independently innovated and researched; ④ technologies with mature and large-scale application, such as hydroelectric power, will not be taken into account; ⑤ for the various factors that affect the development of energy technology, the pathway will follow this sequence of priority: resource – contribution – environment – innovation – feasibility – economy.

The energy strategy research group was divided into four subgroups which included general group, energy saving and fossil energy group, renewable energy group, new energy and nuclear energy group. With the support of Academician Luguang Yan, Shouxian Fang, Jiyang Wang, chapter 1, 2 and 6 were finished by Yong Chen, Daiqing Zhao and Guotian Cai. Chapter 3 and 4 were finished by members of four subgroups. Chapter 3 was finished by Yong Chen, Chuangzhi Wu, Daiqing Zhao and Guotian Cai. Section 4.1 was finished by Yaohua Li, Xuhui Wen and Feng Zhao. Section 4.2 was finished by Yizhuo Han and Zhijian Xiong. Section 4.3 was finished by Guobiao Gu, Liye Xiao, Zhiping Qi, Jianzhong Tong, Li Han, Rong Wei, Shaotao Dai, Xisheng Tang and Hui Guo. Section 4.4 was finished by Chuangzhi Wu, Zhenhong Yuan, Longlong Ma and Yongming Sun. Section 4.5 was finished by Honghua Xu, Jianlin Li, Zhifeng Wang, Meimei Zhang, Songyuan Dai and Fantai Kong. Section 4.6 was finished by Jiyang Wang,Weibin Ma, Zhonghe Pang and Yulie Gong. Section 4.7 was finished by Shudong Wang and Zhongshan Yuan. Section 4.8 was finished by Xiaosen Li and Ningsheng Wang. Section 4.9 was finished by Shouxian Fang, Jiangang Li and Baonian Wan. Section 4.10 was finished by Jiangang Li, Baonian Wan,Yage You, Songyuan Dai and Fantai Kong. Chapter 5 was finished by general group based on Chapter 4 and in depth discussion with every subgroup.

Jun Zhang gave great support in information and material collection. Daiqing Zhao, Lucheng Ji and Guotian Cai served as the project secretary.

From November 2007 to November 2008, the energy strategy research group initiated various efforts in strict accordance with the plan. The process included the followings:

(1) According to the research progress of this project, we held four plenary sessions in Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Institute of Plasma Physics, Chinese Academy of Sciences, Institute of Electrical Engineering, Chinese Academy of Sciences, Institute of Coal Chemistry, Chinese Academy of Sciences in November of 2007, April, May and September of 2008 respectively. In these meetings, the research group discussed structure and idea of the roadmap, the intermediate progress of the roadmap research, the first and revised draft of the roadmap in depth. We reached a relative consensus roadmap which can not only satisfy China's energy demand development but also lead development direction of energy technology. The strategic research report was finished by General Group.

(2) Each thematic group held their own seminars, such as solar power roadmap meeting, electricity roadmap meeting, fossil energy roadmap meeting, nuclear energy roadmap meeting, hydrogen energy roadmap meeting, biomass energy strategy seminar, general group roadmap meeting, etc., to improve the depth and breath of the roadmap research.

(3) We attached great importance to interdisciplinary thinking and learned from other projects which are related to energy technology. We invited some experts in ocean, coal, biological, soil, geology and sustainable development to join us in the fourth plenary.

(4) Through thorough research, consultation, analysis and reference of questionnaires and methodologies, referring to the roadmap of US, Japan, Germany and International Energy Agency, we ensured our high starting point and perspective.

(5) Research groups participated in CAS Roadmap Seminar in October and December 2007, and June 2008.

(6) We accepted the evaluation group headed by Dean Qiheng Hu, we listened to the opinions from those experts, such as Dean Jianzhong Xu, Ruwei Dai, Zhanguo Wang and Fuxi Qian as well as researcher Hejun Yin, Libin Xiang Jing Tian.

(7) In April 2009, we accepted the evaluation given by the experts group of Dean Qinghuan Jin, Professor Xiaoming LI, Fengqi Zhou, Ben Hua, Wenying Li, Jing Ding, and Guilin Piao, headed by Dean Kechang Xie, with Yong Li as the senior engineer. Dean Qili Huang, Yangpingkai Ou, Yaoming Zhang and Professor Dexin He made a written review.

(8) According to suggestion from the experts, the group made careful amendment and improvement of the report. Meanwhile, many young researchers took part in the whole process of the roadmap research. We highlighted the method and practice which cultivated young talents for our energy strategy research.

Throughout the year, the group carried out in depth deliberations as well as discussions and made great efforts. The group identified 10 directions of energy technology to be followed till 2050 and finished the report—*Energy Science & Technology in China: A Roadmap to 2050*. Although we put forward a clear energy technology development roadmap, there are still some unpredictable problems that we didn't plan for, such as the wide-range and long-span of technology. We will state our views further in the postscript of this report.

The research on energy technology development roadmap proceeded under the care and help of leaders in CAS, with Dean Yongxiang Lu as head. Moreover, the Bureau of Planning & Strategy and Bureau of Hi-Tech Research and Development of Chinese Academy of Sciences gave us great support. The Advisory Group, headed by Dean Luguang Yan, Shouxian Fang and Jiyang Wang, participated in the relevant work and provided guidance from beginning to end. The Wuhan Branch of the National Science Library, Chinese Academy of Sciences helped us in information collection, and we would like to express our sincere gratitude.

Finally, we would like to express our sincere gratitude to all the experts who paid efforts in the research.

Research Group on Energy of the Chinese Academy of Sciences

April, 2009

Contents

Abstract

Being the public resource for the survival of human beings and the development of society, energy is the material guarantee for national and regional economic development. Energy is not only economic resource, but also strategic and political resource. The sustainable development of energy directly influences China's security and modernization. However, owing to the prolonged utilization of tremendous amount of fossil fuel, greenhouse gases are emitted and accumulated in the atmosphere. This exacerbates greenhouse effect, which leads to the significant increase in the frequency of natural disasters and extreme climate conditions, and threatens the sustainable development of human society, and hence challenges the energy structure with fossil fuel as its core. In such a condition, China appeals to the development of new and renewable energy and establishment of efficient, economical, clean and sustainable energy supply system, which will push forward the revolution of technology and advancement of civilization and society.

To establish an efficient, economical, clean and sustainable energy supply system which meets the demand of a low-carbon economy, solving science and technology problems is the first priority. Energy has the characteristics of large-investment, multi-link, long-cycle and strong-inertia, once the direction is incorrect or the technology lags behind, the passive situation of being constrained by foreign technology will occur in the following decades. Therefore, to ensure the sustainable development of China's economy and society as well as our modernization, China should establish an innovative energy system that suits China's development demand and characteristics, seize the opportunities of the alteration from fossil fuel to new and renewable energy, narrow the gap between domestic technology and the foreign advanced technology, enter the front rank of global energy technology, and hence support the development of Chinese Sustainable Energy System as well as the formation of Chinese Energy Technology Innovation System.

According to the unified deployment by the Chinese Academy of Sciences, the Energy Strategy Research Group of CAS made up of more than 30 experts was established. From the embodiment of strategic direction and a certain degree of feasibility requirements, the research group drew the roadmaps for future development based on that of the developed countries. Three different periods of development were considered, 2008—2020, 2021—2035 and 2036—2050 respectively, as the time nodes, and set up *Energy Science & Technology in China: A Roadmap to 2050* with the logical pattern of "demand

of energy development→important energy technology issues→important energy technology direction→technology development roadmap→general deployment for energy technology innovation→guarantee for system construction".

For the important energy technology direction and the choice of roadmaps, Energy Strategy Research Group followed five fundamental principles: ① independent R&D technologies which can no longer meet current need, are to be digested and absorbed; ② technologies with promising future only applied in a small scale are to be focused on, researched and to strive for a breakthrough; ③ technologies with significant demand in the future but are still under research and discovery are to be independently innovated and researched; ④ technologies with mature and large-scale application, such as hydroelectric power, will not be taken into account; ⑤ for the various factors that affect the development of energy technology, the pathway will follow the sequence of priority as "resource – contribution – environment – innovation – feasibility – economy".

Energy Science & Technology in China: A Roadmap to 2050 outlines 10 major cutting-edge technologies for development of energy science and new national energy industry in order to meet the needs of economic and social development. The 10 major cutting-edge technologies are the highly-efficient non-fossil-fuel ground transportation technology, the clean and high-added-value coal utilization technology, the power system security and stability technology, the biomass liquid fuel and raw material technology, large-scale power generation technology from renewable energy resources , enhanced geothermal systems technology for deep geothermal resources, hydrogen utilization technology, natural gas hydrate development and utilization technology, the new nuclear power and nuclear waste treatment technology, and the potential energy technology.

Various energy technology obstacles should be overcome in different periods from 2009 to 2050. China's energy science and technology will witness a qualitative leap with 40 years' efforts: National energy industry with Chinese characteristics will be established based on independent intellectual property and provide technical support for energy sustainable development. Great effort should be made to break through key technological barriers, and to advance relevant technology integration, test demonstration and commercialized application. The concrete strategic steps are as follows.

Around 2020, breakthroughs should be made in clean coal technology to establish an industrial system for coal-based energy and chemical engineering, in rail transportation technology and advanced electric vehicles technology to establish a system of commercialized use of electric transportation. While taking the full use of the existing advanced hydropower and EHV power grid, breakthroughs should be made in solar thermal power, solar PV power and wind power generation technology, in order to set up a technological and industrial system with renewable energy as a major source.

Around 2035, breakthroughs in the technology of biomass to liquid fuels should be made and applied to commercial use. Based on the breakthroughs in high-capacity low-loss electric power transmission technology, scattered, unstable renewable energy grid-connected power generation and distributed grid technology, the share of power equipment security protection technology and new grid security protection technology will reach 90%. A new, distributed and independent micro-grid

power system with solar power and wind power generation will be initially established. And breakthroughs in the key technology of new nuclear power generation and nuclear waste processing should be made to establish an advanced nuclear power industrial system with Chinese characteristics.

Around 2050, breakthroughs in the technology of natural gas hydrate, hydrogen, fuel cell car, deep geothermal power and ocean energy generation should be made in order to shape a diversified energy mix including fossil energy, renewable energy, and nuclear power, and thus establish an innovation-based energy industry system with Chinese characteristics.

Energy technology has features of cross discipline, long cycle and big inertia, therefore, the achievement of roadmap relies on great progresses on time sequence, deployment of key areas, linkage between fundamental theory and technology application, and coordinative development between technological competitiveness and manufacturing industry. To ensure remarkable achievements, China must fully arouse the initiatives and creativities, promote high efficient allocation and integration of energy technology resources in the whole society, and establish an energy innovation system with enterprises as its mainstay which combined with production, education and research, to improve the capability of China's independent energy innovation. China needs to strengthen its formulation of policies, regulations standards and research, to strengthen platform of personnel, science and technology, as well as to facilitate protection of investment measures, and to promote energy technology development and innovative system.

1 Research Framework on Energy Science & Technology Roadmap

Being the public resource for the survival of human beings and development of society, energy is the material guarantee for national and regional economic development. Energy is not only a type of economic resource, but strategic and political resource as well. The technological and sustainable development of the energy technology directly influence our nation's security and modernization.

Energy has the characteristics of large-invest, multi-link, long-cycle and strong-inertia. As a major developing country, in order to ensure the rapid and sustainable development of the society and economy, China has to establish an energy science and technology system which can be related to global energy high-tech, possess our own characteristic and match China's basis of domestic resource and demand, in order to support our secure, clean, efficient, economical new energy industry system.

Therefore, China urgently needs to formulate an energy science and technology development roadmap with clear time node and long time span which provides new ideas, guidelines and goals for the independent innovation of energy technology. The research and formulation of energy science and technology development roadmap takes the national objectives as the first priority. Based on the objective law of energy development trend and following the guidance of the "all-round, coordinated, sustainable" view of scientific development, we now strive for strategies and ways that allow the development of energy science and technology to lead the development of urban, rural, regional areas, economy and society, the coordination among human and nature, domestic affairs and opening up.

During the process of formulating the energy science and technology development roadmap, we will thoroughly implement the principles of "autonomous innovation, give prominence to stride over, support development and leading the future", to eliminate the restraint of energy as a bottleneck on socioeconomic development first. We will open our mind, make bold explorations and independent innovation. We will also put forward new ideas, to explore new science and technology, to infer the key core R&D technology model application, to promote advanced energy technology into productivity, to support the modernization of energy systems for sustainable development, and to make basic, strategic, perspective contributions on the whole.

1.1 Basic Framework of Energy Roadmap

1.1.1 Basic Framework

The research and formulation of the energy science and technology roadmap is based on the field of energy science and technology. It puts forward the demand for energy science, describes the future vision, analyzes science and technology mission, assesses and selects the achievable technology and its implementation, determines the direction achieving the objectives of energy science and technologies, helps decision-makers to determine the future of energy science and technology development strategies. This energy science and technology roadmap seeks to propose a clear direction, specific tasks, obvious focus and strong feasibility.

The energy science and technology roadmap includes the basic framework of the time line, composing elements, time nodes and time priority, etc.

1) One time line. The energy science and technology roadmap is a plan map based on the time nodes, describing the goals or problems of science and technology from now to a specific time in the future.

2) Five elements. The energy science and technology roadmap is made up of five elements, namely the demand for energy science, energy science missions, energy technology options, research and development plans, and policies and resource guarantee: energy science demand refers to the demands of social and economic development for energy science and technology; energy science missions refer to the tasks to be fulfilled in order to meet the scientific needs and technological objectives; energy technology options mean the consideration of what kind of energy technological support we need to complete the task of science; research and development plans mean to select key technology R&D projects to develop feasible plans; policies and resource guarantee refers to the needs of personnel, financial, and material resources guarantee and management on the way to complete the energy science and technology objectives.

3) Time node. Time nodes refer to a certain objective to be achieved at a target time. The development of energy science and technology roadmap is set for the time span between now and 2050, including three times node at the year 2020, 2035 and 2050. At different time nodes, the choice for characteristics and technologies varies. The objective to be fulfilled by 2020 will focus on the integration and enhancement of existing mature technologies; by 2035, on key technological breakthroughs, demonstration and application; by 2050, on forward-looking and innovative technologies.

4) Priority. In order to meet the needs of a single science demand, one may have to complete many tasks. Different tasks, hence, may have a variety of technical support. The energy science and technology roadmap will identify technology priorities and importance in accordance with objectives of the contribution of these tasks.

1.1.2 Current Development at Home and Abroad

In the recent ten years, the energy science and technology roadmap has been used widely as a foreseeable strategic planning approach. Many developed countries have formulated energy science and technology roadmaps for their own scientific research and technological development of energy planning and forecasting, as well as the national energy strategic policy[1-7]. For example, the Australian renewable energy technology roadmap, the EU renewable energy technology roadmap, the United States, United Kingdom, Switzerland, South Korea, South Africa, Japan, France, Canada, Brazil, Argentina and other countries' fourth-generation nuclear energy systems technology roadmap, Japan's energy strategic technology roadmap to 2030, Japan's energy strategic science and technology roadmap to 2100, the Australian carbon dioxide capture and storage – research, development and demonstration of technology roadmap, South Korea fuel cell and hydrogen technology roadmap plan, etc. In energy science and technology roadmaps these countries formulated, the short-term ones plan for a duration of 5 years to 15 years, longer ones 20 to 30 years, or even 100 years, such as Japan's energy strategic science and technology roadmap to 2100.

China's energy technology research and development of the roadmap is still in the initial stage of work. The Chinese Academy of Sciences, Chinese Academy of Engineering, Ministry of Science and Technology have launched energy-related scientific and technological pathway research. China is in urgent need to conduct in-depth research on the whole energy system and the roadmap of different energy technologies in different periods in the future, integrate multi-resources, predict in certain target areas the development of energy technologies, provide a framework for energy technology research and development as well as coordinate the research and development work at different levels.

1.2 Basic Principles and Preparation Process of the Energy Roadmap

1.2.1 Basic Principles

Based on the comprehensive integration of views of stakeholders, the energy science and technology roadmap is a process trying to target up those views into the objectives. It combines vertically the objectives, the tasks with the resources, and unifies horizontally the past, present and future, to describe the present and predict the future. It is a complicated system program with the participation and hence consensus of multi-disciplinary experts.

The formulation of the roadmap for energy science and technology focuses on the correlation and coordination of three main points. First of all, energy is the material basis for economic and social development. So, the energy science and technology roadmap must be consistent with our basic national conditions, stage of economic and social development and national strategic demand closely and embodies the huge demand for solving China's energy sustainable development. Second, we should put forward clearly different types of clear scientific and technological development routes, with distinctive characteristics of the development goals on region, resource and objective. Third, as energy science and technology is a multidisciplinary, cross-cutting science, the impact of the bottlenecks of energy technology development and scientific issues should be made clear in the research. On the basis of the analysis on different energy technologies in the cross-points and common, we should put forward key technologies and describe a scientific, innovative and perspective science and technology development roadmap.

1.2.2 Preparation Process

The basic process of preparation for the energy science and technology roadmap includes the major energy scientific and technological development demand analysis, main energy scientific and technological analysis and options, classification of energy science and technology roadmap and suggestion on the implementation of the roadmap.

Phase one. Comprehensively analyze the energy development at home and abroad, the current situation, development trend of the future and the possibility of a strategic choice; put forward the needs and tackle the problem of the key issues on the basis of full imagination about the future transportation, construction, industrial and other economic and social development of rural areas.

Phase two. For a major demand for energy and the key issues, we take full advantage of the phase characteristics of energy technologies, give attention to both the level and the speed of international energy technology development, and put forward directions and technologies able to guide scientific and technological progress of China's energy, the development of China's national energy industry and the tremendous energy needs of China.

For technologies at different level of maturity, our basic principle to select the energy science and technology roadmap is as follows: technologies developed independently but unable to meet the needs of technology in time will be digested and absorbed; technologies with promising prospects but have technical problems or no application will be researched and strive for a breakthrough; technologies with large demand in the future but are still in the potential forefront of science will be researched and innovated independently;

technologies with mature and large-scale application, such as hydroelectric power, will not be taken into account.

For various factors that affect the development of energy science and technology, the energy science and technology selection and development will follow these priorities: resource – contribution– environment – innovation – achievement – economy.

We focus on the key science and technologies that are selected to go through the commercial application process, divide them into basic research, technological breakthroughs, technology maturity, commercial application, and draw up the roadmap. We particularly emphasize on the impact to contributions, degree of independent innovation and characteristics of China's new national formation of the energy industry in 2035 and 2050.

Phase three. According to the set research and development time in science and technology roadmap, we determine the overall deployment of new energy technologies till 2050, and provide the basis for the development of the strategic plan at different stages.

Phase four. According to the choice of the technological route, we analyze the component of energy technology innovation system and draw lessons from home and abroad. From the combination point of view, we propose the guarantee policies needed (in terms of system, resources and personnel) for the secured realization of the technology roadmap, and propose recommendations for later research and establishment of research platform.

2 Trend and Key Issues of China's Energy Development to 2050

2.1 China's Modernization and Energy Development

2.1.1 The Progress of Energy Technologies for Socio-economic Development

Energy is material foundation for the survival and development of human society. Throughout the history of human society, every significant progress of human civilization came with the transition of energy types and advancement of energy technology. Human development and utilization of energy have a long history. It has gone through the generation of traditional renewable energy and firewood, and the generation of coal and oil. Driving the technological advances, mankind will enter a generation of new energy and renewable energy sources.

Before the 18th century was the generation of firewood. In primitive society, before the discovery of how to use fire, human beings had mainly relied on chemical energy stored in the food. The discovery of fire and the use of wood to make a fire were landmark of the start of using energy, and a major leap forward in the conquest of nature and human social development. Branches, weeds and so on were used as fuel. Production activities mainly relied on manpower, animal force, simple hydro-driven and wind-driven machinery.

With the evolution of civilization and the development of the country, organic fuel such as vegetation and wood could no longer meet the needs of economic and social development. The energy shortage constricted urban and economic development, and population growth. Therefore, people made efforts to discover and use a variety of fossil energy. The industrial revolution in 18th century, especially the invention of the steam engine and the application of power promoted the use of coal greatly. Coal took the place of firewood and gradually became the major source of energy. Energy use dominated by coal lasted to the middle of the 20th century, when human had experienced the coal-driven steam engine era.

Oil was exploited in the 1870s, and the maximum share of oil in total energy use was 45% in 1970. The natural gas was exploited in 1880. Its share in total energy use has been grown consecutively since 1880.

Propelled by the wide applications of internal combustion engine in different kinds of industries, consumption of oil and natural gas was higher than that of coal in the 1950s, which marked that energy use had entered into a generation of oil and the internal combustion engine. From the development of steam engine to internal combustion engine shows the successfully conversion from thermal energy to mechanical power.

Due to the emergence of energy shortage and the potential for depletion of fossil energy, humans have to adjust energy structure dominated by oil towards a structure of diversified energy sources, and start to develop and utilize new and renewable energy, such as nuclear, solar, wind, ocean, biomass and geothermal energy. Several new and renewable energies, such as nuclear power, solar energy, bio-energy tend to replace fossil fuels dominated by oil and coal. This tendency will become a major revolution in energy technology.

Therefore, science and technology is a vital driving force in improving energy and power technology, and will lead to revolutionary changes in technology systems and socio-economic development. Social development is characterized by energy transition. From the animal labor to wind and hydro power, from steam engine to internal combustion engine, a lot of breakthroughs have been made in human society. Breaking through limitations of organic economy, human marched into the industrial civilization from agriculture civilization. There will be a new leapfrog in human society with the improvement and wide application of new and renewable energy technologies.

2.1.2 The Development Progress of China's Modernization

China started the reform and opening-up policy from 1978. This policy adjusted the economic development strategy, and put forward a "three-step" development strategy of modernization in 1987: the first step is to double the gross domestic product in 1980 and to solve the problem of food and clothing for the people; the second step is to redouble the gross domestic product by the year of 2000, and to help people achieve lives with level of well-off society; the third step is to realize basic modernization by the mid-21st century.

By the end of the 20th century, with 20 years' development, China's social and economic situation have changed profoundly: firstly, the country's economic strength was improved, according to comparable price, the gross domestic product in 2000 was more than 6 times of the figure in 1980, with an annual average growth rate of more than 9 percent; secondly, with the speeded-up process of industrialization, the industrial structure developed from low-level to senior and from the serious imbalance to the basic and reasonable direction, the proportion of first industry declined and the complete industrial system was built, China has transformed from the early stages of industrialization into the medium term; thirdly, people have become well-off. In the 1980s century, China had basically solved the problem of food and clothing, and stepped forward to the well-off society in the 1990s. By the end of the 20th century, 75% of the residents have earned well-off lives, about 13% of the residents close to a well-off level and about 12% of the remaining residents still far away from well-being.

Therefore, by the end of the 20th century, China's socio-economic development has realized the first two steps of strategic deployment on modernization in accordance with the three-step plan. From the beginning of the 21st century to 2050, China will implement the third-step strategic plan of modernization to build a well-off society within 20 years, and to realize modernization by the mid-21st century. As a result of the very significant differences between provincial and regional economic development, all regions of China will realize modernization goal inconsistently (Table 2.1)[8].

Table 2.1 The realization timetable of China's modernization

Region	The realization timetable of modernization	Region	The realization timetable of modernization
China	2050	Shaanxi	2052
Shanghai	2015	Henan	2053
Beijing	2018	Jiangxi	2053
Guangdong	2021	Guangxi	2054
Tianjin	2026	Inner Mongolia	2055
Jiangsu	2033	Anhui	2055
Fujian	2034	Chongqing	2055
Liaoning	2035	Xinjiang	2055
Zhejiang	2036	Sichuan	2055
Shandong	2041	Shanxi	2056
Heilongjiang	2041	Yunnan	2057
Jilin	2045	Ningxia	2060
Hainan	2048	Gansu	2062
Hubei	2048	Qinghai	2065
Hebei	2052	Guizhou	2070
Hunan	2052	Tibet	2075

Source: Strategy group on sustainable development of Chinese Academy of Sciences. Strategic concept of Chinese modernization process.Beijing: Science Press, 2002

In the first 20 years of the 21st century, China's main objectives and tasks of social economic development are as follows: firstly, to double the gross domestic product in 2020 with an annual average increase of 7.2%, and to basically realize the industrialization and further enhance the industry development and technical level, to realize the fundamental technological transformation of agriculture and the significant regulation of industrial and employment structure caused by the improvement of technology and development of the tertiary industry; secondly, to speed up the urbanization process and promote the transfer of the rural population to non-agricultural industries, in 2020 urbanization rate will be more than 55%, and it is expected to reach 75% in

2050; thirdly, to develop an open economy, actively participate in international cooperation and competition with a larger scope, wider area and a higher level. During the period from 2001 to 2007, results of the actual development of China surpassed the target to be met, with an average annual growth rate of more than 9%. By 2020, more than 1.4 billion people will establish well-off society and the basic realization of industrialization. By the middle of this century, there are nearly 1.5 billion people who realized modernization and this is the world's largest social transformation process in the history. China may face various difficulties and challenges during the process. Energy security is one of the important challenge.

China's Major Strategic Task of Modernization

The implementation of China's modernization is a huge strategic system. The nature of the put-forward and operation is to achieve "a high degree of upgrade on the overall national goal". Within certain period of time, China's modernization must ultimately meet the requirements of the following seven basic strategies: comprehensive national strength should have a "step-by-step improvement", the bottleneck which restricting the country's development should be "effectively overcame", acts of state in the new strategic framework should "normative an orderly operation", the effectiveness of the national ability of integration will get "essential improvement", the quality of life in a new phase can realize "overall optimizing", universal moral standards and social order level should "substantive progress", and China will be able to present "a successful example of management" for the international community.

Facing new challenges in the 21st century, our modernization process must address a series of major strategic issues: ① to meet the challenges of economic globalization by enhancing China's comprehensive national strength and international competitiveness; ② to accelerate industrialization by information technology, complete a new round of structural adjustment and improve the overall economic efficiency and our ability to gather wealth; ③ China must rely on the effectively accumulation of social wealth to meet the "rational needs" of all citizens, which is to continuously improve the quality of life; ④ China must fully rely on scientific and technological progress to ensure national security (information security, financial security, economic security, ecological security, social security, food safety and national security), maintain social stability and create a peaceful, stable economic environment, social environment and ecological environment; ⑤ China must rely on science, technology and education to improve the quality of our people in science and technology comprehensively and change a heavy population pressure into huge human resources; ⑥ China must improve the level of management by technological innovation and find a successful way for sustainable development of conditions of a relatively poor resource and fragile ecological environment. China's success in achieving modernization in the 21st century depends on overcoming the following five bottlenecks: the deviation between population reproduction and reproduction of material, the gap between the resource value and ecological value of production ,the balance between the free possession of environment capacity and conservation, the balance between economic efficiency and co-ordination of social equity, the mainstream in knowledge-based economy and information industries in the national development.

It is expected that in the next 50 years China's modernization process will follow the basic principle of sustainable development, and go through three major steps of the non-symmetry "zero growth" to a virtuous circle of sustainable development, to reach the comprehensive level of developed countries. The first step is to achieve the "zero growth" of population (natural increase rate) in number and size by 2030, while in the corresponding direction to achieve the improvement of the quality of population greatly, to alternate bearing the tremendous pressure of population into enjoying the rich human resources, to provide fundaments for the continuous material and spiritual civilization. The second stage is to achieve the "zero growth" consumption rate of material and energy, at the same time achieving greatly enhancement of social wealth in the corresponding direction and realize the "four-fold leap" global goal. The third level is to achieve the "zero growth" of ecological and environmental degradation rate in 2040, while in the corresponding direction to achieve improvement of environmental quality and ecological safety. To achieve ecological objective of "beautiful earth" and "zero growth" of ecological and environmental degradation rate. It is the last and the most difficult stage among three major strategies.

Source: Chinese Academy of Sciences Research Group on Sustainable Development Strategy. Strategic concept of China's modernization process. Beijing: Science Press, 2002

2.1.3 Important Issues about the Impact of China's Modernization Process in the Future Energy Development

(1) Urbanization and Urban Construction

Urbanization and industrialization are the two basic tasks for modernization, which has been approved by the experience of countries over the world.

The reports of the United Nation indicate that the world's urbanization rate in 2008 will reach 50%. Compared with the early stage of global industrialization in 1800, the urbanization rate (5.1%) has increased more than 40%. In 2050, the world's population will increase from the current 6.7 billion to 9.2 billion, among which 6.4 billion people will live in cities. The amount of rural population will reduce from the current 3.4 billion to 2.8 billion.

Urbanization is accompanied with industrialization in the history. China promoted industrialization in a special historical condition and economic system in the past which made urbanization fell behind industrialization. The urbanization rate at the end of 1949 in China was 10.6%. In early 1950s, industrialization and urbanization proceeded relatively fast. In 1957, the urbanization rate was only 15.4%, while in the 21 years from 1957 to 1978 it was 17.9%, only increased 2.5%. Urbanization has speeded up since the 1980s. The urbanization rate reached 44.9% in 2007.

Urbanization is a fundamental issue of China's economic development in the 21st century. In March 2006, "the eleventh five-year plan" raised to increase the urbanization rate from 43% to 47% in the year 2010. With the average increase rate of 0.8%, the urbanization rate in 2020 will reach 56%. According to China's strategic scheme of modernization, the modernization rate should increase from 36.2% in 2000 to above 75% in 2050. In this speed, more than 10 million rural residents will be transferred into urban areas every year. Till 2050, nearly 500 million rural people will transfer to cities (Table 2.2).

Table 2.2 China's future population growth and its proportion of urban and rural areas

Population \ Year	2000	2005	2007	2010	2020	2035	2050
Total population (billion)	1.27	1.31	1.32	1.36	1.44	1.47	1.44
Urban population (billion)	0.46	0.56	0.59	0.64	0.81	0.96	1.08
Proportion of urban population(%)	36.2	43.0	44.9	47.0	56.0	65.0	75.0
Rural population (billion)	0.81	0.75	0.73	0.72	0.63	0.52	0.36
Proportion of rural population(%)	63.8	57.0	55.1	53.0	44.0	35.0	25.0

However, the task of urbanization is not only to increase the urban population and improve the urban development standards, but also to create a basic resource environment which can support this development. From 1985 to 2000, China's urban population increased by 0.83 times, urban land, water resource and primary energy consumption increased by 0.66 times, 2 times and 1.1 times respectively. Urbanization has brought profound changes in housing, employment, lifestyle and consumption patterns, etc. At the same time, serious resource and environmental problems are also presented. Among them, energy supply and energy security will determine the prospects of urbanization. The impact of China's urbanization on energy consumption is mainly embodied in two aspects:

On one hand, the infrastructure construction can boost energy development. With the development of urbanization, infrastructure and large-scale residential construction require a large amount of high energy-consuming products such as steel, cement, electricity and chemicals. These high energy-consuming products can greatly stimulate the growth of energy consumption. In 2007, calculated by household population, China's urban per capita residential floor area was around 28 square meters. The well-off standard for urban per capita housing area was 35 square meters. China plans to build new construction area of nearly 30 billion square meters increased by more than 2 billion square meters per year. This needs a strong backing of solid urban industrial and energy foundation.

On the other hand, energy used for residents' daily life has increased, and the energy structure has been optimized. The energy consumption of Chinese urban residents is 3 times more than the energy consumption of rural residents. Urban residents mainly use gas, electricity and commercial coal as energy for daily life. The acceleration of urbanization means more rural residents move to urban areas. Thus, the former non-commercial energy (such as firewood and stalk) will be replaced by other commercial energy. At the same time, with the improvement of living standard, the durable commodity for residents will increase rapidly. Take the increasing demand for cars as an example, urban residents only possess 0.5 cars per one hundred family in the end of 2000 and the number climbed to 4.32 in the end of 2006. If every 2 Chinese possess a car (equal to the per capita standard in America), the whole nation will possess 700 million cars; If every 3 person possess a car (equal to the per capita standard in Japan), the whole nation will have 400 million cars; If every 5 person possess a car (equal to the per capita standard in Holland), the whole nation will have 200 million cars. Significant growth of cars will lead to the growth of energy consumption in China.

The Development of China's Urbanization

Since reform and opening up, urbanization in China has greatly speeded up. As the economic grows fast and stable for a long time, China has formed an "economic acceleration" which boosts China to step into the stage of "fast urbanization". Till the end of 2007, China's urban population has amounted to 594 million, and the urbanization rate has reached 45%.

Development of China's population from 1978 to 2007

Year (year end)	Total population (ten thousand)	Urban areas		Rural areas	
		Population (ten thousand)	Proportion (%)	Population (ten thousand)	Proportion (%)
1978	96,259	17,245	17.92	79,014	82.08
1980	98,705	19,140	19.39	79,565	80.61
1985	105,851	25,094	23.71	80,757	76.29
1990	114,333	30,195	26.41	84,138	73.59
1995	121,121	35,174	29.04	85,947	70.96
1996	122,389	37,304	30.48	85,085	69.52
1997	123,626	39,449	31.91	84,177	68.09

(Continued)

Year (year end)	Total population (ten thousand)	Urban areas		Rural areas	
		Population (ten thousand)	Proportion (%)	Population (ten thousand)	Proportion (%)
1998	124,761	41,608	33.35	83,153	66.65
1999	125,786	43,748	34.78	82,038	65.22
2000	126,743	45,906	36.22	80,837	63.78
2001	127,627	48,064	37.66	79,563	62.34
2002	128,453	50,212	39.09	78,241	60.91
2003	129,227	52,376	40.53	76,851	59.47
2004	129,988	54,283	41.76	75,705	58.24
2005	130,756	56,212	42.99	74,544	57.01
2006	131,448	57,706	43.90	73,742	56.10
2007	132,129	59,379	44.94	72,750	55.06

Source: National Bureau Statistics of China. China statistical yearbook 2008. Beijing: China Statistics Press, 2008

(2) New Socialist Countryside Construction

At present, China has more than 700 million of rural population, accounting for 55% of the total population. Even if industrialization and urbanization progress smoothly, rural population will still have around 600 million in 2020, and around 500 million in 2035. In 2050, there will be nearly 400 million people live in rural areas. At present, there is a large income gap between urban and rural residents. The income of urban residents is 3 times of that of rural residents'. If take some non-monetary factors into account, including housing, education, health care, social security and other social welfare, the income gap will be even larger. National policy has shifted to focus on rural development, to solve the problems of the farmers, and to boost the coordinated development of urban and rural areas. The main goal of new socialist countryside construction is "production development, well-off life, civilized rural atmosphere, clean village, and democratic management". This means that rural areas should also receive the normal national energy public service. However, China's rural energy infrastructure is not advanced enough, and non-commercial energy has been used as daily energy by rural residents for a long time. About 11.5 million people in the nation still couldn't use electricity. Commodity energy consumption for daily life per capita of rural residents is 1/3 of the consumption of urban residents. Many rural residents still use stalk, firewood and some other traditional inefficient biomass which burns directly as energy (Table 2.3). These laggard energy using methods has impaired the improvement of living standard for rural residents, and the overuse firewood and stalks as fuel have damaged the ecosystem seriously.

Table 2.3 Energy using condition of rural areas in China

Year	Energy for daily use in rural areas(10^4 tce)						Energy for daily use per capita (kgce)	Including	
	Commercial	Non-commercial	Including			Total		Commercial	Non-commercial
			Methane	Stalk	Firewood				
1995	7,675	20,214	108	10,092	10,013	27,889	325	89	235
2000	5,839	20,574	162	12,360	8,052	26,413	327	72	255
2006	9,930	27,986	509	17,791	9,686	37,916	514	135	319

Source: Department of Industry and Transport Statistics, National Bureau of Statistics, People's Republic of China. China energy statistical yearbook 2007. Beijing: China Statistics Press, 2008

If traditional energy continues to be the main rural energy, it will directly affect China's sustainable economic development and modernization process. There are difficulties for conventional energy to meet the huge demand of both rural and urban areas. However, rural areas have rich renewable energy resources for development and utilization. On one hand, China can capitalize on the local resources and adjust measures on local conditions to supply electric energy for remote areas and daily-use energy for rural residents. On the other hand, biomass resources in rural areas could be converted into commercial energy and to turn renewable energy into a rural characterized industry. It can extend the agricultural industry chain efficiently, improve agricultural efficiency, increase peasant's income, improve the rural environment and promote the rural economy as well as the social sustainable development.

(3) Regional Coordinate Development

One of the basic content of modernization is the realization of social justice. It is an unremitting long-term major task to reach balanced development between regions and to ultimately achieve prosperity. China's development is unbalanced in population distribution, resource storage and economic situation since ancient times (Table 2.4). Distribution of energy resources has obvious regional characteristics: oil and gas mainly distribute in the northeast, northwest and parts of sea areas; coal mainly stored in north China; 70% of hydropower resources are stored in southwest and northwest. Densely populated east, central and southern China only possess 1/5 energy resource of the total amount in China. In addition, there is a large contrast between the occurrence degree of regional energy resources and economic development level.

China proposed the overall strategy for coordinated regional development, in accordance with the carrying capacity of resources and environment, development foundation and potential, to play the comparative advantages so as to gradually form a regional coordinated development pattern with clear major function, positive interaction between east, central and west, as well as a narrowing gap between public service and people's living standards.

Table 2.4 Contrast of regional economy and energy reserve(including coal, oil and gas) in China in 2005

Region	Province included	Gross domestic product (10^8 yuan)	Energy reserve (10^8 tce)	Per capita GDP (yuan)	Per capita energy reserve (tce)
Northern China	Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Shandong	47,271	1,443	19,400	591
Northeast China	Liaoning, Jilin, Heilongjiang	17,140	120	15,900	112
Eastern China	Shanghai, Jiangsu, Zhejiang	46,272	120	22,800	59
Central China	Anhui, Jiangxi, Henan, Hunan, Hubei	27,675	114	10,800	44
Southern China	Guangdong ,Guangxi, Fujian, Hainan	33,905	11	18,600	6
Southwest China	Chongqing, Sichuan, Guizhou, Yunnan, Tibet	16,158	215	8,300	110
Northwest China	Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang	9,363	416	9,900	440

Source: National Bureau Statistics of China. China statistical yearbook 2006. Beijing: China Statistics Press, 2006

In line with the carrying capacity of the resource environment as well as current developing density and potential, coordinating the future population distribution, economy layout, land use and urbanization format, China's land space can be divided into four principal functional districts: optimizing development district, key development district, restricted development district and prohibited development district. According to the adjustment and perfection of regional policy and performance evaluation system of the principal function positioning, the space development sequence should be standardized and properly formed. China should also insist on taking the implementation of western development, the revitalization of northeast China and other old industrial bases, promoting the rise of the central region and getting the eastern region to take the lead in development as the overall strategy for regional development to improve the interaction between the regional coordination mechanisms and form a rational pattern of regional development.

The western region needs to speed up the reform and opening up process and to enhance the self-development capacity through the national support and self efforts as well as the regional cooperation. The northeastern region needs to revitalize by accelerating industrial restructuring as well as the reorganization and transformation of state-owned enterprises. The central region should rise with the industrial development advantage as a link between east and west main relying on existing basis to upgrade the industry level, and promote industrialization and urbanization. The eastern region should take the lead in raising the capacity of independent innovation, optimizing and upgrading the economic structure and growth pattern, improving socialist market economic system and to help promote the development of central and western regions through its development and reform.

Working Plan for China's Principal Functional Districts

National Development and Reform Commission (2007) No.27, *Advices of the State Council on Plans for the National Principal Functional Districts*, provided practical advices on the planning of national principal functional districts in accordance with the requirements put forward by the 2006 Central Economic Work Conference, that is "sub-level planning to promote the work of the principal functional districts", aiming at providing scientific basis for the promotion of regional coordinated development.

Establishing the principal functional districts means that it is needed to co-ordinate the future population distribution, economic layout, land use and urbanization patterns according to different carrying capability of regional resources, the current developing density and potential. The national land space should be divided into four categories—optimizing development, key development, restricted development and prohibited development areas, to clear the position of the principal functional districts and the developing direction, to take control of the development intensity and sequence, to improve the development policy and gradually form a coordinated development pattern of population, economy and resource environment.

Establishing and promoting principal functional districts is a vital action to implement the scientific outlook on development and construct socialist harmonious society. It's also conducive to people-oriented development, narrow the gap of public serves among regions, boost the regional coordinated development. It's beneficial to guide the economic layout, population distribution and the carrying capacity of resource environment to form a spatial balance of population, economy and resource environment. It's helpful to reverse the trend of environmental degradation from source, to adapt and mitigate the climate change, to save resource and protect environment. In addition, it's beneficial to break the administrative divisions, formulate and implement targeted policies and performance evaluation system to enhance and improve regional administration.

The plan of principal functional districts is strategic, fundamental and binding. It's the fundamental basis in terms of space development and distribution for overall plan of national economic and social development, population, region, city, utilization, environment protection, ecological construction, water shed, marine function zoning, sea-use, food production, transportation, disaster prevention and mitigation.

The national principal functional district planning is composed with state principal functional district planning and provincial principal functional district planning which means it has two levels: national and provincial. The state principal functional district planning is commanded by National Leading Group for State Principal Functional District Planning abbreviate to leading group and all autonomous regional and municipal people's governments. The planning period will last till 2020, and will adjust through mid-term evaluation. The planning period of provincial principal functional district planning which is commanded by autonomous regional and municipal people's government will last till 2020. The major task for state principal functional district planning is to confirm the amount, location, range, positioning, development direction, management principle and regional policy of principal functional districts of all levels and types on the basis of national land space analysis.

Source: National Development and Reform Commission [2007]. Working plan for China's principal functional districts. http://ghs.ndrc.gov.cn/ztgnqghjyhome/jtgnqjyxc/t20070801_162702.htm

As the basis of economic development, energy will undergo a significant structural change with the change of economic structure. On one hand, the demand pattern will change greatly. The total energy consumption of northeast, central and western regions will increase rapidly with the development of economy. With the adjustment and upgrading of industrial structure, the energy structure of eastern regions will be further optimized. On the other hand, the supply structure will also have a tremendous adjustment. The further development of fossil fuel and renewable energy (mainly water power in southwestern regions and non-water power in northwestern regions such as wind power, solar power and geothermal power) of western regions will greatly change the energy supply structure of China.

(4) Environment and Health

Since reform and opening up, China has experienced rapid economic development, enriched material culture, meanwhile, people's expectations upon living environment and health security have risen. However, the irrational exploitation and utilization of natural resources, especially large-scale use of fossil fuels dominated by coal, has resulted in serious environmental pollution and ecological damage. For example, among 500 cities tested in 2007, 281 cities suffered from acid rain, accounting for 56.2% of the whole, mainly concentrated in the south of the Yangzi River, Sichuan province, east part of Yunnan province, including most part of Zhejiang, Jiangxi, Fujian, Hunan, Chongqing province, as well as Yangzi River and Pearl River delta[8]. Destruction of the ecological environment has negative effect on public health and has become more and more constrained to the development of sustained economy and harmonious society.

In the past century, many observations indicated that the climate on earth is undergoing a significant change with global warming as the main characteristics. The fourth assessment report of IPCC clearly pointed out that the main reason of global warming in nearly 50 years was caused by greenhouse gases, such as carbon dioxide, methane, nitrous oxide generated by human activities[9]. Against this major background of global warming, climate in China also changed significantly over the past century. The annual average temperature increased by 0.5–0.8°C. The last 50 years is a particularly evident warming period. In the future, global warming in China will be more serious. Chinese scientists forecast that compared with 2000, the annual average temperature in China will increase by 1.3–2.1°C in 2020, and 2.3–3.3°C in 2050[10].

(5) Development of Low-carbon Economy

Low-carbon economy is based on low energy consumption, low pollution and low emission. Transition towards low-carbon economy has become the world's general trend of economic development. The United States, Japan, the United Kingdom, the European Union, and many other developed countries are making efforts to change the mode of economic growth, and gradually transit to low-carbon economy, to develop low-carbon energy technologies, to change high-carbon energy consumption into low-carbon energy consumption.

One of the most importance essence of low-carbon economy is to use energy efficiently, to develop energy in a clean way and to pursue green GDP. The key is the development of energy technology, innovation on emission-reduce technology, industrial structure, institutional system, and the fundamental conversion of the concept of human survival and development. Low-carbon economy is the goal of China's future economic development. Some cities have started pilot program of low-carbon economy. The transformation of low-carbon economy will exert an important effect on energy supply and consumption structure of China with new challenges and requirements on the future energy technology.

2.2 Development Trend of China's Energy Demand to 2050

2.2.1 Analysis of Energy Development

(1) World Energy Development

Energy is an important material foundation for the survival and development of human society. Throughout the history of the development of human society, every significant progress of human civilization has been accompanied by the improvement and transition of energy. Human development and utilization of energy and fossil fuels has a long history. There are three major periods in this history, period of firewood, coal and oil. At present, the three major fossil fuels—coal, oil and gas are still the most important primary energy in the world. In 2006, the world's total primary energy consumption amounted to 15.56 billion tons of standard coal. Coal, petroleum, natural gas, nuclear energy and water accounted for 28.4 %, 35.8%, 23.7%, 5.8% and 6.3% respectively. Over the past 100 years, developed countries have completed the industrialization and consumed a lot of energy resources in this process. At current stage, the developing countries are stepping into the stage of industrialization. There is no doubt that energy consumption will increase with economic and social development. Inevitably, this will greatly increase pressure on the global energy system. Future world energy consumption will continue to grow and huge differences remain in different countries and regions. Asia, Africa and Latin America will grow faster than Europe, North America and Japan. Profound changes will be taken in the pattern of world energy (Table 2.5).

Table 2.5 Future energy and population development tendency in major countries and regions

	Year	Population (million)	Total energy consumption (million tce)	Per capita energy consumption (tce)	Per capita CO_2 emissions (t)	Energy consumption per ten thousand yuan GDP (tce) (1995 constant price)
World	2020	7,496	19,227	2.6	3.9	2.4
	2030	8,082	21,854	2.7	3.6	2.1
	2050	8,864	27,751	3.1	2.9	1.7
Europe	2020	605	2,864	4.7	6.2	1.9
	2030	606	2,964	4.9	5.4	1.6
	2050	586	3,541	6.0	4.4	1.4
North America	2020	376	3,737	9.9	12.9	2.3
	2030	404	3,720	9.2	10.4	1.9
	2050	444	4,063	9.2	7.2	1.6
Japan	2020	162	1,024	6.3	7.5	1.9
	2030	161	1,106	6.9	6.7	1.7
	2050	154	1,373	8.9	5.9	1.6
Asia	2020	3,995	6,944	1.7	3.1	2.4
	2030	4,258	8,766	2.1	3.6	2.1
	2050	4,511	12,230	2.7	4.3	1.7
Africa and Middle East	2020	1,439	2,110	1.5	2.6	4.1
	2030	1,692	2,661	1.6	2.8	3.8
	2050	2,177	4,990	2.4	3.6	3.4
Latin America	2020	649	1,371	2.1	2.9	2.2
	2030	700	1,634	2.3	3.2	2.0
	2050	756	2,177	2.9	3.3	1.7

Sources: World Energy Technology Outlook - 2050 WETO-H2, European Commission, 2006, ftp://ftp.cordis.europa.eu/pub/fp7/energy/docs/weto-h2_en.pdf

Fossil fuel still remains the main source of energy up to date. The huge energy consumption will result the run out of petroleum and natural gas in less than half a century. With regard to coal, it will be used out in 100 or 200 years. No matter what kind of conventional energy structure , the energy crisis is becoming more and more serious. At the same time, large-scale development and utilization of fossil fuels have led to certain environmental problems, such as climate change and ecological damage, posing direct threat to sustainable development of human society. In this context, many countries and regions take clean and pollution-free renewable energy as integral part of its energy strategy, propelling exploitation of renewable energy and new energy to replace conventional fossil fuels. Particular in February 2005, the *Kyoto Protocol* was put into force, which became a new impetus of all countries, especially in Europe, to develop renewable energy. Some European countries such as Spain and Ireland have amended policies and regulations of renewable energy. The United States updated energy bill in August 2005, which continues endorsing renewable energy and hydrogen energy development. There are more than 30 developed and 100 developing countries in formulated a national renewable energy development goals. In 2005, China also made great stride in full-fledging renewable energy regulations and policies. The *Renewable Energy Law* is promulgated in February and entered into force in January 1, 2006.

(2) China Energy Development

China is rich in energy resources, with relatively abundant fossil energy resources, dominated by coal. In 2006, the proven coal resources in China is 1034.5 billion tons, ranking the third in the world. Proven oil and gas resources are relatively insufficient, oil shale, coal-bed methane and other unconventional fossil energy reserves have great potential to exploit. China has abundant renewable energy resources such as solar energy, hydropower, wind energy, biomass energy. The theoretical reserves of hydropower resources is equivalent to an annual generation capacity of 6.19 trillion kW·h, among which the economic generation can reach an annual production of 1.76 trillion kilowatts, taking up 12% of the world's water resources, listed the first in the world. But large population result in low per capita energy resources. China's per capita coal and water resources account for only 50% of the world's average. Per capita oil and natural gas resources are only 1/15 of world's average. Arable land resources in China are less than 30% of the world's average, constraining the large-scale development of biomass energy. Compared with resourceful countries, China has complicated geological exploration conditions for coal, mining, oil and natural gas resources which are buried deep. China falls short of these high-tech requirements. Water resources which are concentrated in the southwestern mountains have yet to be developed since they are far away from load centers along with major challenges and costs that developers may face. There is still long way to go to conduct higher level non-conventional energy development and achieve higher economic benefits.

China's energy industry has experienced a rapid growth since the reform and opening up. It is manifested mainly in following aspects. Firstly, the total energy consumption increased from 570 million tons of standard coal in 1978 to 2.46 billion tons in 2006. But as a result of China's large population, per capita energy consumption was still very low. In 2006, per capita primary energy consumption of the world's average, the United States, Japan, Germany, France, the United Kingdom and China were 2.4,11.1,5.8,5.7,6.0,5.4,1.9 tons of standard coal respectively. Secondly, the consumption structure has been optimized. The proportion of coal in primary energy consumption fell from 70.7% in 1978 to 69.4% in 2006, other energy rising from 27.8% to 30.6%, renewable energy and nuclear power rising from 4.0% to 7.2%, and oil and gas also increased. Thirdly, China has formed an energy supply pattern with a coal as the main body, electricity power as its core, oil, gas and renewable sources developing in all areas. We basically established a relatively sound energy supply system. Fourthly, the results of energy conservation are highly visible. During 1980-2006, China reached a 9.8% annual growth of GDP at the cost of 5.6% energy consumption. Per 10,000 yuan GDP energy consumption dropped from 3.39 tons of standard coal in 1980 to 1.21 tons in 2006 (at 2005 constant prices). But compared with developed countries, there is still a large gap (Figure 2.1). According to exchange-rate-derived GDP, in 2006, China's per 10,000 dollars GDP of primary energy consumption was 2.5 and 7.2 times as the world and Japan respectively. Fifthly, progress has been made in environmental protection. China attaches great importance to energy policy to reduce and effectively control the process of energy development and environmental problems.

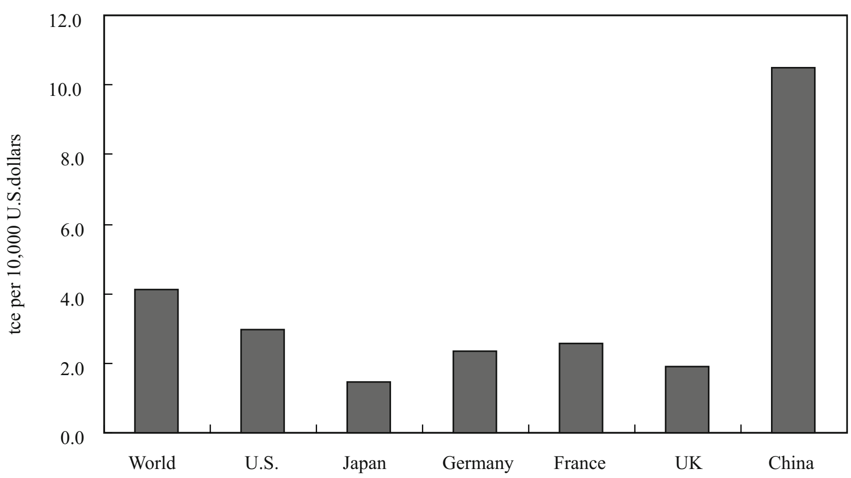


Fig. 2.1 Comparison of primary energy consumption per 10,000 dollars GDP of major countries in 2006
(GDP at 2000 constant price was calculated by exchange-rate)
Source: International Statistical Yearbook for 2008

There are huge inter-regional differences in view of natural conditions, population, and economic development. Energy production is mainly concentrated in north China. Primary energy production in northwest and northeast China accounts for more than 70% of the whole country while southwest, central, east and south China is less than 30%. Shanxi, Shandong, Heilongjiang, Inner Mongolia, Henan, Shanxi and Xinjiang are China's important energy production base. Energy consumption is mainly concentrated in the east and north of China. Total primary energy consumption of north China, northeast and east China account for 62%, while northwest and southwest less than 4%. There is a space unbalance between energy production and energy consumption. Resources in north, northwest and southwest areas which are in surplus have been transferred to the northeast, central, east and south China. Several key projects have taken shape, such as "north-south and west-east coal transmission project", "west-north and northeast-south oil gas diversion", "offshore oil and gas development" and "west-east electricity transmission project", forming an energy transport system which has involved plenty of provinces(Table 2.6).

Table 2.6 Comparison of energy consumption and energy supply in different region of China

			North China	Northeast China	East China	Central China	South China	Southwest China	Northwest China
Primary energy production	Total production (10^4 tce)		88,582	22,574	8,572	22,376	5,125	22,525	25,734
	Com-pose (%)	Coal	84.7	64.0	91.7	88.0	40.6	92.0	72.0
		Oil	8.1	35.0	5.7	5.7	41.1	0.1	24.9
		Natural gas	7.1	0.2	0.1	0.1	1.3	0.9	1.1
		Others	0.1	0.8	2.5	6.2	17.0	7.0	2.0
Energy con-sumption	Total consumption (10^4 tce)		75,420	32,141	38,422	32,790	17,875	10,845	19,091
	Com-pose (%)	Coal	87.1	64.0	72.6	87.8	76.0	95.3	66.4
		Oil	11.9	35.3	27.2	11.0	22.2	1.0	32.1
		Natural gas	0.1	0.2	0.1	0.1	0.2	0.9	0.8
		Others	0.9	0.5	0.1	1.1	1.6	2.8	0.7

Source: National Bureau Statistics of China. China statistical yearbook 2006. Beijing: China Statistics Press, 2006

As the largest and fastest-growing developing countries, China has become the world's second largest energy producer and consumer, increasingly rely on energy import. China created a broad space for development in international energy market and has brought great impact as well.

2.2.2 Trend Outlook of China's Energy Demand by 2050

(1) Growth Movement of Total Energy Requirements

In recent years, research institutes both home and abroad have predicted China's future energy consumption. For example, in 2007, Academic Division of Chinese Academy of Sciences[11] and International Energy Agency[12] made predictions about energy consumption aggregation and structure of China (Table 2.7, Table 2.8). However, both China and the world changes quickly with a lot of uncertainties, it is hard to depict the future of China's energy accurately. One of the uncertainties is China's economic growth rate. Although it is difficult to draw a clear blueprint about energy demand during China's modernization in 2050, we do our best to predict the long-term energy demand in this roadmap.

Table 2.7 Development and outlook of China's primary commodity energy consumption and composition

Time	Population (hundred million)	Consumption (10^8 tce)	Ratio in world's consumption(%)	Energy structure(%)					
				Total fossil energy	Coal	Oil	Nature gas	Water and nuclear power	Renewable energy excluding water
2000	12.7	13.0	9.8	93.2	66.1	24.6	2.5	6.8	—
2005	13.1	22.3	14.7	93.4	69.6	21.1	2.7	6.6	—
2020	~14.5	~29.0	—	~88	~60	~22	~6	~8	~4
2050	~16	~50.0	—	~74	~40	~23	~11	~11	~15

Note: "~" means approximately.

Table 2.8 Development and outlook of China's energy consumption and composition in future

	Energy demand(10^6 tce)						Proportion(%)					
	Reference scenario		Alternative policy scenario		High growth scenario		Reference scenario		Alternative policy scenario		High growth scenario	
	2015	2030	2015	2030	2015	2030	2015	2030	2015	2030	2015	2030
Total primary energy demand	4,073	5,456	3,919	4,651	4,479	6,701	100	100	100	100	100	100
Coal	2,670	3,427	2,490	2,631	2,910	4,157	66	63	64	57	65.0	62.1
Oil	776	1,154	740	933	894	1,497	19	21	19	20	20.0	22.3
Nature gas	156	284	180	321	179	394	4	5	5	7	4.0	5.9
Nuclear	46	96	63	171	49	117	1	2	2	4	1.1	1.7
Hydroelectric power	89	123	107	156	93	143	2	2	3	3	2.1	2.1
Biomass and waste	321	324	319	364	336	330	8	6	8	8	7.5	4.9
Other renewable energy	17	47	20	74	19	61	0	1	1	2	0.4	0.94

China has just stepped into high-speed industrialization and urbanization. For a long time, China will continue strong growth momentum and huge energy demand. Since reform and opening-up in 1978, the growth rate remained at 9.3% for 29 years. China now is well on track to implement strategic deployment of modernization. If there are no special irresistible socio-political, economic, cultural, military, natural disasters internationally and domestically, per capita GDP in 2010 will double the 2000's level; by 2020 it will quadruple 2000's level, reaching the world average level of developing countries, according to constant prices and taking into account the natural growth of population factors. By 2030, it will increase by nearly 10 times and become a newly industrialized country, achieving modernization with industrialization. It is projected that China will enter into post-industrial era and being a member of of developed country by the middle of the century.

In light of national condition, following the trend of urbanization, new rural construction and balanced development among regions, we made following basic assumptions about China's future(Table 2.9).

Table 2.9 Conditional situation of China's future development

Index \ Year	2006—2010	2010—2020	2020—2035	2035—2050
GDP annual average growth rate/%	9	7.5	6	4
Population/hundred million	2010: 13.6	2020: 14.4	2035: 14.7	2050: 14.4
Reduction of energy consumption per 10,000 yuan GDP	In 2010 energy consumption per 10,000 yuan GDP decreases by 20% compared with 2005	In 2020 energy consumption per 10,000 yuan GDP decreases by 30% compared with 2010	In 2035 energy consumption per 10,000 yuan GDP decreases by 60% compared with 2020	In 2050 energy consumption per 10,000 yuan GDP decreases by 40% compared with 2035
Energy consumption elasticity coefficient	0.70	0.50	0.35	0.15

Note: Energy consumption elasticity coefficient is set on the basis of annual growth rate of GDP, population and energy efficiency improvement.

Based on the above assumptions, total energy consumption in China will reach 31, 45, 61, 66 hundred million tce respectively in 2010,2020,2035 and 2050. It will be fast initially and slowing down gradually. Energy consumption per capita will amount to 2.3, 3.1, 4.1, 4.6 tce.

(2) The Trend of Energy Structural Changes

China's energy consumption will be restricted by serious resource supply and environmental problems. By 2050, China's coal and oil consumption will reach 4.5 billion tce and 1.2 billion if energy consumption increases in light of the energy structure in 2006. However, future supply of coal will be restricted by resource, mining and transport capacity along with backward autonomous technology. China is facing serious oil supply bottlenecks so that more than 600 million tons of oil gap will be filled only by import in 2050. At the same time, massive fossil energy consumption will lead to huge carbon dioxide emissions. Coal and oil consumption will produce 14.4 billion tons of carbon dioxide, close to the half of the current world's total carbon dioxide, which will seriously damage China's ecological environment and let China face pressure from the international community in terms of climate change. In addition, such a large-scale energy consumption will be affected by power grid safety technology, transportation, natural disasters, national security and so on. Therefore, the fossil energy—coal, oil and natural gas always fall short of demand; environmental pollution and greenhouse gas emissions deteriorate ecological damage. It is urgent to promote rapid development of energy technologies and improve the quality of China's energy consumption, adjust energy structure to cut down fossil energy and scale up renewable energy, new energy and nuclear energy.

According to requirements of China's mining capacity of coal and carbon dioxide emission reduction, the future supply of coal should be less than three billion tce. Under national planning, the installed capacity of nuclear power will reach 72 million kilowatts by 2020, 5% of a national total installed capacity. If nuclear power installed capacity increase to 200 million kilowatts after 2035, accounting for 10% of total and amount to 300 million kilowatts in 2050, taking up about 12% of the total, proportion of nuclear in the total energy will increase from 0.8% in 2006 to 4% in 2020, 7% in 2035 and 10% in 2050. Under national planning, renewable energy will take up at least 15% of total energy by 2020 and speed up with technology upgrading. Taking into account all above assumptions, we drew Fig. 2.2 to depict China's changes in primary energy consumption structure by 2050.Several fossil fuels, like coal, petroleum and natural gas scale down from 93% in 2006 to 80% in 2020, 66% in 2035, 45% in 2050, respectively. The aggregation of coal will be 2.5, 2.7 and 2 billion tce in 2020, 2035 and 2050, respectively. A number of key energy technical bottlenecks will be overcome with scientific advancement, such as natural gas hydrates, solar power, deep geothermal energy utilization. Now, China is well on track to optimize energy structure, moving towards a low fossil energy era.

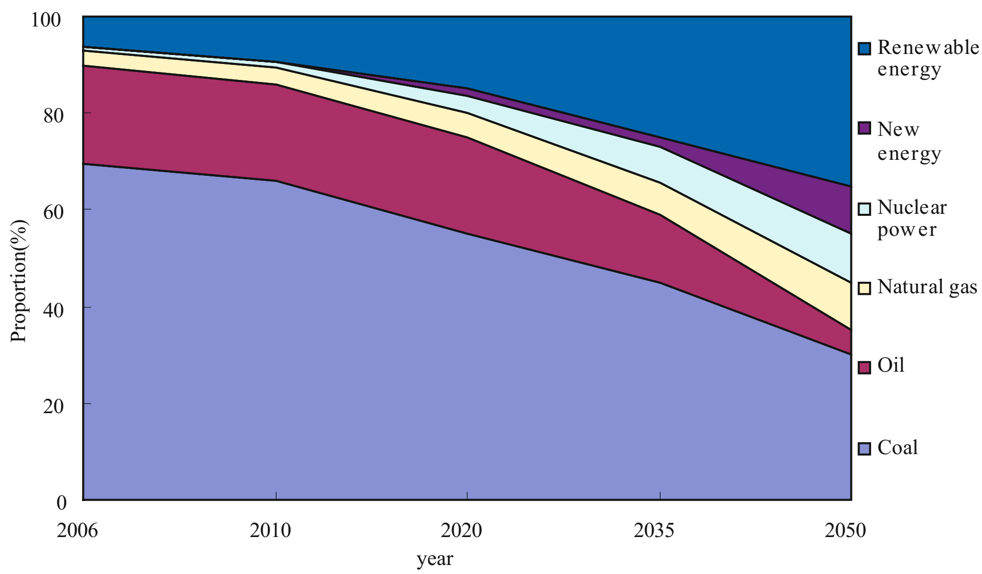


Fig. 2.2 Primary energy consumption structure changes to 2050 in China
(Renewable energy includes hydropower, wind, solar, biomass, ocean energy, geothermal energy. New energy includes gas hydrates, hydrogen and nuclear fusion, etc.)

In light of above predictions, coal, oil, nature gas emit 2.66, 2.02, 1.47 tons CO_2 per tce respectively[13]. Calculating at this way, China's carbon emission will surpass North America, Europe and Japan after 2020(Fig. 2.3). However, compared with energy structure in 2006, it cut down a lot of carbon emission(Fig. 2.4). Of course, per capita CO_2 emission of China is just equivalent to the world average level, much lower than North America, Europe and Japan.

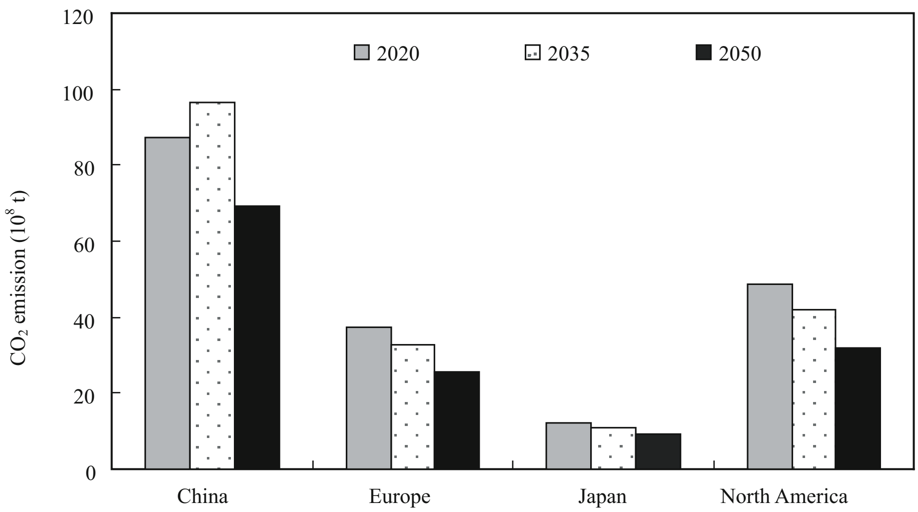


Fig. 2.3 China's CO_2 emission in the future and comparison with developed countries

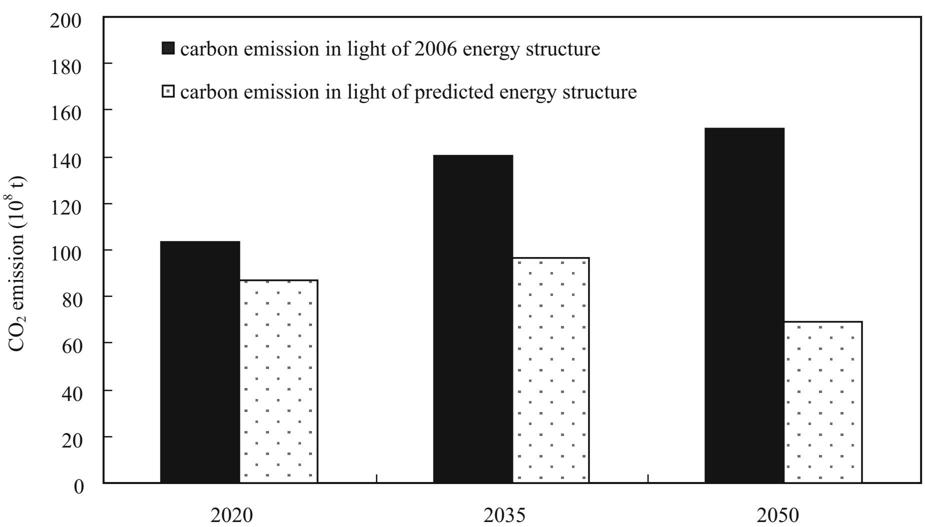


Fig. 2.4 CO_2 emission comparison of two different scenarios in China

To achieve a low-carbon economy, China has to take more stringent measures to reduce share of fossil energy and increase the share of nuclear energy, renewable energy and new energy in total energy consumption.

2.3 Key Issues Concerning about Chinese Energy Development to 2050

To guarantee a smooth progress in China's modernization, the key issue in future energy development is to ensure the security in supply and utilization of future energy. Efforts should be directed by Scientific Development View, commanded by energy ecological civilization; China should adhere to the policy of "Conservation Priority, based on domestic demand, diversified development, rely on science and technology, protect the environment, mutually beneficial cooperation", and establish the energy supply and consumption system that is stable, economical, clean, and safe. To realize this goal, we need to adjust energy structure rapidly, as well as have stable transition to a sustainable energy utilizing system to support the sustainable development of economy and society. Our main task and key issue is how to tap and save energy while reducing emission. The starting points of China's energy development for the future are the following four aspects.

2.3.1 Efficient Utilization of Energy

China is a developing country with a large population and insufficient natural resources. To achieve social and economic sustainable development, it is necessary for us to pursue the coordination of resource-economical development, take an active role in restructuring economy, adjusting industrial structure, and controlling energy consumption increased. Also, Chinese government should encourage energy conservation technology developing and energy saving products, and upgrade energy managing capability by polishing regulation and legislation to improve energy utilization efficiency.

Most of China's final consumption of energy commodities concentrate on the following sectors: industry, construction, transportation, storage, post & communication, wholesale and retail trading, catering trade and urban living. Industrial energy consumption takes up 70% of the total amount of national energy consumption. In China, there is still a long way to go compared with developed countries. The 11^{th} 5-year plan proclaimed that energy consumption should be reduced by 20% per GDP unit by the year 2010, and main areas of energy conservation that are to be realized in industry, transportation, construction, and conservation quantity in construction contains 21% of the total conservation in the 11^{th} 5-year period, namely to save more than 100 million tons of standard coal.

In 2007, Development and Reform Commission has issued *The General Work Plan for Energy Conservation and Emission Reduction*, that has clarified the target, task and general requirements for Energy Conservation and Emission Reduction, and put forward a series of measures from aspects of structure upgrading, key projects, technological supporting, strengthening regulation, institutional protecting, to carry out "Energy Conservation and Emission Reduction".

High-efficiency in energy utilization has a profound influence on the future of energy. To reach its goal as "quadruple the economic growth, double the energy efficiency", high-efficiency energy utilization in both urban and rural area is decisive. The main issue is how to promote the energy conservation in industry, construction and transportation sector.

2.3.2 Developments and Applications of Energy in Rural Areas

Energy consumption from rural areas only takes up 8% of the commercial energy final consumption. To guarantee the effective supply of energy in the process of modernization in rural areas, two aspects should be considered. Firstly, it is needed to provide rural areas with advanced energy utilization technology, and change the current situation where rural areas heavily depend on conventional energy under a backward energy system. Secondly, rural areas are abundant in renewable energy resource. China should advocate and direct them to effectively develop and utilize renewable energy according to local conditions.

2.3.3 Constructions on a Low-carbon Energy Structure

It has already been an irreversible trend to save energy, develop low-carbon economy, and construct new energy structure around the world. Low-carbon economy is an economic pattern based on low energy consumption, low pollution, and low emission. It is human society's another great progress after agricultural and industrial civilization. Low-carbon economy is in essence high energy utilization efficiency and clean energy structure, whose core parts are innovation in energy technology and institution, and the fundamental change in people's concept on existence and development. Therefore, China should constantly modify its energy structure to have a transition to sustainable energy system, and decrease the share of fossil energy while increasing the portion of renewable energy. China should promote the coordinated development of energy and environment and construct the low-carbon energy structure in order to build a resource-economical and environment-friendly society.

(1) Fossil Energy

Energy industries of coal, oil, natural gas and other fossil energy have finished the constructions of a large number of large-scale energy bases. However, the future of energy is not promising in China. In 2020, only coal could meet the domestic demand. Oil, natural gas and uranium could only support the energy consumption till 2010. The trend of the depletion of fossil fuels is irreversible, and the lack of energy limits the improvement of supply capability. In the future, there will be limited room for exploring and exposing fossil fuel, and have been a huge damage to the environment. Therefore, we should prioritize the high-efficiency utilization of fossil energy. In the coming half century, China will pay more attention to how to develop the technology to utilize coal in an efficient, clean and low-emission way, in order to make coal as our main energy within the allowance of resource, environment, and climate change.

(2) Renewable Resources

China's hydropower station has been developed in river basins on three classes of terrain stairs respectively, focusing on the upriver of Yellow River, middle and up part of Changjiang River and its branches, Lancangjiang, Red Water River, Wu River basins, etc. We have built a series of large hydropower bases while promoting the development of smaller hydropower bases. These bases play an important role in solving the problem of power and environmental protection in rural areas. China is actively developing renewable energy. In the future, apart from going on with hydropower, we will propel the utilization of solar power, wind power, biomass energy, geothermal energy, ocean energy and other non-water renewable energy. By putting these kinds of energy into mass production, renewable energy industry is vitalized.

To enhance the utilization of renewable resource, China should take full advantage of the abundant renewable resource in the vast western part of China and the desert area, where build large-scale comprehensive, high-efficiency energy utilization bases. For another, we will innovatively apply renewable energy to energy saving in construction and transportation, to tackle with the severe shortage in liquid fuel and increasing energy consumption caused by the rapidly increasing energy using in future construction and transportation in our modernization.

(3) Nuclear Power and New Alternative Energy Sources

We should also develop new energy that is more efficient, easier to be acquired and more environmental friendly, such as nuclear power, hydrogen energy, gas hydrate, and fusion energy, to replace the massive utilization of fossil energy step by step.

2.3.4 Long-distance Energy Transportation

Because of the unbalanced distribution of fossil energy, China has formed a coal transportation channel from North to South, West to East; basically formed a backbone gas and soil pipeline network and key regional network; a power transportation network mainly through the construction of regional power network and the promotion of power networks interconnection to realize a nation-wide connected energy distribution network, which has formed a energy transportation system running through the North and the South, across the East and West and connecting overseas. At the same time, renewable and new energy also face the unbalancing problem, especially the storage and stability of power network. One of the key issues in our future energy is to expand large-capacity, stable, safe energy storage and distant transportation system, and bridge the energy supply and energy demand.

West-East Power and Gas Transmission Project

"West-East Power Transmission Project" is one of the symbolic projects and key components of West Region Development. This project will exploit power resource in Guizhou, Yunnan, Guangxi, Sichuan, Inner Mongolia, Shanxi, Shaanxi and other provinces in the west, and transmits the power to those provinces of power shortage, for example, Guangdong, Shanghai, Jiangsu, Zhejiang, and Beijing-Tianjin-Tangshan region. "West-East Power Transmission Project" is an important policy in implementing West Region Development, and it will transform the advantages on resource in the west to the advantages on economy. By taking advantage of the abundant natural resource in the west, the demand for start-up capital of West Region Development could be resolved. Meanwhile, the power transmitted provides the east with clean, high-quality, reliable and less expensive power, to fuel the development in the east. The project consists of three routes: north route, middle route, and south route. The southern grid line transmits the power generated from Wu River, Lancang River, Nan Pan River, Bei Pan River, Red Water River, and the thermal power generated from Mine Mouth Power Plant, to Guangdong. The middle route transmits power to east China from the Three Gorges and the hydropower from Jinshajiang River and its branches. The northern grid line sends the hydropower from upriver of Yellow River, and thermal power from Shanxi and Inner Mongolia to Beijing-Tianjin-Tangshan Region.

The National Congress implemented "West-East Gas Transmission Project", whose investment only second to the Three Gorges, in February, 2,000. This project marks the beginning of West Region Development. Tarim Basin, Qaidam Basin, Shanxi-Gansu-Sichuan Basin enjoy 2600 billion cu. meters natural gas, taking up 87% of onshore natural gas resources in China. Especially in Tarim Basin, Xinjiang, contains more than 8,000 billion cu. meters natural gas, 22% of the total natural gas storage. Kuche area in the north of Tarim Basin gathers more than 2,000 billion cu. meters natural gas, where is the richest natural gas area in the Basin, and has the potential to become the world class resources development area. The discovery of natural gas in Tarim Basin enables us to be one of the countries rich in natural gas, following Russia, Qatar, Saudi Arabia.

"West-East Gas Transmission Project" includes a 4,200 km trunk pipeline with an investment of 140 billion yuan. The project has the longest pipeline with the largest diameter of 1,016 millimeters, the design pressure is 1MPa, the design capacity is 12 billion cu. meters per year. The whole pipeline applied the automatic control, covering the Central Plains, East China, Yangtze River Delta. Starting from the oil and gas fields in Lunnan area of Tarim Basin, stretching east-ward through large and medium cities like Kuala, Turpan, Shan-shan, Kami, Liuyuan, Jiuquan, Zhangye, Wuwei, Lanzhou, Dingxi, Xi'an, Luoyang, Xinyang, Hefei, Nanjing, Changzhou, the terminal station of the pipeline is Shanghai. The project was accomplished and put in use in 2004.

The second line starts from Huoerguosi, via Xi'an, Nanchang, going down south to Guangdong, and ends in Shanghai, running through Xinjiang, Gansu, Ningxia, Shaanxi, Henan, Anhui, Hunan, Jiangxi, Guangxi, Guangdong, Zhejiang, Shanghai, 13 provinces, autonomous regions, and municipals, stretching 4,859 km. Together with its branches, the total length is over 7,000 km. This line is supposed to be accomplished in 2010. The gas in this pipeline is imported from Turkmenistan, Kazakhstan and other central Asian countries, with domestic gas as backup and supplement. The third line in planning is supposed to start from Xinjiang, Jiangxi, to Fujian, transmitting gas from Russia and Northwest China to energy demanding Yangtze River Delta and Pearl River Delta.

The "West-East Gas Transmission Project" is beneficial to industrial structure adjustment, promoting the co-development of the east and west, improving people's livelihood in the Yangtze River Delta and along the pipeline, and solving the atmosphere pollution problem. This project creates a favorable condition to transform the resources advantages to economic advantages, and has a strategic meaning to propel the economic development in Xinjiang and other western regions.

Source: http://www.zytv.cc/Article/HTML/20080225001651-34.html
http://news.xinhuanet.com/newscenter/2008-11/13/content-10354380.htm

3 Important Science & Technology Issues and Technical Direction of China's Energy Development to 2050

3.1 Important Science & Technology Issues of China's Energy Development

With growing demand for energy owing to the sustainable and rapid economic growth, the restriction of energy on human economic and social development and the impact on the environment have become increasingly clear. The sustainable development of energy has become a major strategic issue for the overall situation of China's economic and social development. The establishment of China's sustainable energy system is a long-term and arduous process which needs strong support from energy science and technology innovation. It also needs to be integrated, unified, and coordinated under the guidance of scientific development strategy.

To deal with the main task and key issues of the future energy development characterized by cutting costs and reducing emissions in China, first of all, we need to solve the scientific problems in improving efficiency, reducing pollution and assuring security of energy technologies and energy systems. On the other hand, we need to solve the major scientific problems in the process of establishing new energy and renewable energy systems of China, to explore the possible ways of large-scale using of non-fossil energy, to research and develop new theories and new methods as theoretical basis for the development of the energy of high-tech and energy equipment manufacturing industry with China's independent intellectual property rights, and lay the foundation for solutions to the sustainable development of China's energy.

Considering the demand development, China's future energy technology is faced with key problems like energy conservation, improving energy efficiency and the use of energy in rural areas, adjusting the energy structure and others. The more long-term problems are the large-scale development of new energy and renewable energy, construction of national large-sized clean energy base, ensuring the sustainable development of energy supply, mitigating and tackling climate change.

3.1.1 The Status Quo of China's Energy Technology Development

In China's development of energy technology, fossil energy use has formed a more mature technology, while the technology of using renewable energy and new energy is in the rapid development of breakthroughs, innovation, industrialized demonstration, and promoting application of demonstration; the growing demand for the safe transmission and distribution, and storage technologies of the energy (mainly electricity) is becoming more and more urgent. Table 3.1 summarizes the current status of the development of energy technologies in China.

Table 3.1 Current status of the development of energy technologies

	Energy sources	Status quo	Problems
Fossil energy	Coal	Coal heating and power generation technology is relatively mature. High added value utilization of coal, that is, coal chemical technology, is developing rapidly. Coal gasification technology is relatively mature. The direct and indirect liquefaction technologies of coal have been demonstrated in an industrialized scale.	Energy consumption in the whole industry is relatively high. The problem of pollutants has not been completely resolved. The clean coal technology in China still has a long way to catch up with international advanced technology. Highly-efficient power generation relies on the introduction of technology, lacking of self-innovation technology and its equipment industry.
	Oil	Application technology is mature. Petrochemical industry is mature. China has made great progress in petroleum geology, geophysical exploration, oil drilling, deep-sea oil and gas exploration, petroleum well logging, oil extraction technology, ground works and other professional techniques.	Oil exploration and exploitation technology still has a long way to catch up with international advanced technology. The quality and structure of petroleum refining products is still relatively backward. There is a lot of space to improve production and reduce costs. The development of oil alternative energy technology is still slow.
	Natural gas	A series of technologies have been initially formed, such as the development of carbonatite gas reservoir, the development of low permeability gas reservoir technology, the development of low-sulfur and medium-sulfur gas reservoir technology, the development of anomalous high pressure gas reservoir technology, the development of circular gas injection technology of gas condensate reservoir and so on. Distributed CHP, cold CHP and other new technological applications of natural gas are widely used.	The exploration and mining technologies are needed to be further developed and improved.

(Continued)

	Energy sources	Status quo	Problems
Electricity	Electricity	China has basically formed electricity technology system which includes power production, transmission, energy storage and distribution.	Grid loss is high and can be reduced. The reliability and stability of power system remains to be further improved. In order to meet the penetration of renewable energy into the grid, smart grid technologies needs to be developed. Besides, the electric transportation technologies is one of the most important technology to be developed to meet the changes of energy system, and the related new materials technology needs to be further developed.
Renewable energy	Solar	The utilization and market of solar thermal for home-use are relatively mature. The research and development of solar thermal power generation system has started. Solar photovoltaic energy is rapidly growing.	Technical specifications, national certification standards for technology and product quality, corresponding regulations, and quality monitoring system of solar thermal power generation system have not yet formed; the research of high-quality, highly-efficient solar building integrated-technology is relatively inadequate; silicon-based solar cells, and even production of some thin-film solar cells and other key equipments, are dependent on foreign imports; the development of advanced photovoltaic technology is slow, highly-efficient, low-cost, and environmental-friendly; photovoltaic technology demands further technological breakthroughs.
	Wind energy	The construction and industrialized development of wind farm is progressing significantly; the indigenous production of megawatt-class wind turbine units was achieved on the whole.	The design technology of MW-class WTGS and some key equipments are still dependent on imports; advanced ground-based experimental test platforms and testing wind farms are yet to take shape.
	Biomass energy	We have seen the progress of fuel heating, marsh gas CHP, direct-fired biomass, gasified power generation, to the extraction of liquid fuels and chemical raw materials. The technology is maturing, and advanced energy plants studies and cellulose liquid fuels studies are making in progress with international related researches.	The utilization of wastes from agriculture and forestry is low; the related research of selection and cultivation of energy plants needs to be further developed; there is a gap between China's research of algae biomass energy conversion technology and the advanced international level; the conversion of cellulose into biological enzyme of liquid fuels and research and development of catalysts are below the advanced international level.
	Water	The technology is basically mature.	Environmental impact studies need to be strengthened.

(Continued)

	Energy sources	Status quo	Problems
Renewable energy	Geothermal energy	The development and utilization of geothermal resources have a long history. The exploration technology is relatively mature. There are markets using shallow geothermal based on heat pump technology.	The technology of developing and utilizing deep geothermal resources is below international standards; sets of technology for deep geothermal energy using enhanced geothermal systems remain to be developed; the core technologies of high-capacity heat pumps for shallow geothermal heat use is still relying on imports.
	Ocean energy	Ocean energy research has been improving in full swing, especially the technology of wave energy power generation has reached the international advanced level.	Storm-proof, corrosion-resistant materials, independent power systems and other issues need to be further researched and developed.
Nuclear energy	Nuclear energy	We have a relatively complete system of the nuclear industry, nuclear power plant construction has been fastened. Key technologies of experimental fast breeder reactors and high-temperature gas-cooled reactors have made important progress.	Being incapable of independently producing core and large-scale equipments; researches on the third and fourth-generation advanced reactors are far below the advanced international level.
New energy	Hydrogen	The research of hydrogen energy has been basically synchronous with the international community.	The research of extraction and storage technology of hydrogen should be speeded up. Fuel cell research has not yet to be large-scale, and the network of hydrogen production, storage and transportation has not been formed.
	Natural gas hydrate	The fundamental and applied fundamental researches of natural gas hydrate has been carried out; after the United States, Japan and India, China collected samples of gas hydrate through national R&D program as the fourth country.	In the natural gas hydrate R&D, we are still in the phase of evaluations, explorations and indoor simulative mining of hydrate resources, and we are below the advanced international level; the system of simulating large-scale R&D platform is to be built; it has not yet entered the pilot phase.
	Nuclear fusion	Participating in ITER, a new generation of superconducting tokomak EAST in China has been completed and put into operation, fusion researches in China have made significant progresses.	Superconducting magnets, heating diagnosis, cladding technology, remote control, tritium technology, materials and other key issues have not been broken through.

3.1.2 The Science and Technology Requirements Impacting China's Future Energy Development

(1) Energy Conservation and Energy Efficiency Improvement Technology

Carry out the basic research of energy-consuming methods and theories which make a substantial energy-consuming reduction in metallurgy, building materials, chemical industries and other high energy-consuming industries, and carry out basic research of energy-saving design of buildings and advanced energy-saving heating systems.

Carry out the research of new energy-storing materials and energy-storing technology, develop large-capacity power-storing technology and the technology of distributed power systems, continuously research and develop new grid-controlling technology, information technology and management skills. Combine them organically to realize intelligent exchanges from power generation to power consumption, to optimize power production, transmission and use systematically, and to build a "secure, automatic-responding, economical and clean" intelligent grid system.

Develop clean and efficient energy-converting material and a new system of converting clean energy to improve the energy conversion efficiency. Carry out basic research of safe, long-term heat-insulating materials, environment-purifying materials and antimicrobial materials. Significantly reduce energy consumption in China's building, and control its growth.

China's dependence on imported oil is over 50%, while the import of auto fuels accounts for nearly 50% of the overall. Oil consumption in transportation as well as environmental problems is becoming increasingly serious, so we must develop electric vehicles, alternative energy vehicles, new railway transportation and other electrified transportation technologies, and build a new generation of fuel-efficient and partially oil-substitutable transportation system.

(2) The Deep-seated Exploration, Exploitation and Clean Use of Fossil Energy

As for exploring technology of resources, the basic scientific issues of exploring and exploiting fossil energy include the followings:

—To reveal the occurrence and movement laws of tectonic stress fields, geothermal fields, coal bed gas, and deep-seated karst water influencing the development of deep-seated coal mines according to China's occurrence laws of deep-seated coal resource, to establish theory and technology systems of highly-efficient ore-finding and rapid detection, to provide theoretical foundations and technical means for safe and efficient deep-seated coal mining, and the development of coal-bed methane.

—To study the oil and gas pool-forming mechanism of typical superimposed basin in western areas, and its accumulation process, effect, superposition and complex according to basic researches on mechanisms, development and distribution laws of pool-forming of China's oil and gas, to come up with the prediction theory of the formation and distribution of oil and gas in superimposed basin, to provide a scientific basis for oil and gas exploration in superimposed basin in western China.

—To study the reservoir fluid distribution and reservoir type of carbonate reservoir, reveal the rules of reservoir fluid flow, and provide theoretical basis for the exploitation of carbonate reservoir.

As for technologies of coal utilization and conversion, the basic scientific issue is to research environmental chemistry in energy conversion process, to research and explore the basic scientific issues in the use of fossil resources, related to new principles, new ideas or new technologies of sulfur, nitrogen, heavy metals and other pollutants integration (coupling) removal, and realize the clean use of fossil resources. This mainly includes: the molecular structure of coal, the pore structure of coal, the occurrence and removal of harmful elements from coal, the directed transfer and conversion technology of coal, and basic research in catalysis, applied basic research and techniques on monomers of coal polymers and carbon materials; efficient R&D of coal-burning technology and advanced burners, revealing the formation mechanism of coal-burning pollutants and forming its control technology, and promoting China's coal-burning technology to be efficient, clean, and energy-saving; responses to CO_2 and its technology demands.

As for oil and gas utilization technologies, we should develop new theories and methods of efficient exploitation and utilization of oil and natural gas, conduct basic researches on green and efficient oil processing and petrochemical industry, study related new responses, new conversion mechanisms, new catalysts and new reaction processes based on petroleum processing and petrochemical industry techniques, and provide a theoretical basis and technical support for clean and efficient processing and utilization of China's oil resources.

(3) Power Network Security and New Energy-storing Technologies

Power grids are ties linking power generation and the users; they lead to the functioning of the electricity market and the realization of large-scale optimal allocation of power resources. China's power resources are mainly distributed in the west, while the burdens are mainly distributed in the eastern part, the ill-matched two sides decide that the development pattern of China's power systems is "power transmission diverted from the western to the eastern regions, the northern and the southern regions supply each other with electricity, building networks across the whole country". We are heading to the direction of the extra-large-scale development, and this needs urgent power transmission and distribution, and studies on safety technology of power grids' operation, and we will further enhance the automation, information and modernization of the power systems.

Safe and stable operation is crucial to large power grids. First of all, new material technologies, such as superconducting materials, nano materials, high-temperature-resistant and durable macromolecular materials, ceramic materials and so on, are more and more widely used in power technology; especially superconducting power technology is playing a very unique role. Application of superconducting power technology could significantly improve the quality of electricity and the safe, reliable and stable operation of large power grids, and also significantly reduce the loss of power grids and the size of electrical equipments. Secondly, the flexible control of power system, intelligentization and multi-functional integrated modularization of electrical equipments are becoming increasingly clear, and needs for micro-sensor technology, the technology of real-time measurement and rapid data transmission, and real-time simulation technology are more demanding. Thirdly, with the growing power generation, the power per unit of electric power equipments is increasing, and large power equipments are becoming more efficient and cost-effective, but the direct result is that as soon as there are problems of equipment security, the system operation will be greatly influenced, and even causing safety incidents of power grids. Therefore, we need to study the key technology of power systems, which has transporting capacity of 1–1.5GW and short-range heavy-duty power lines of 2GW; and also develop 750kV EHV, 1000kV UHV AC transmission technology, as well as ± 800kV UHV DC transmission technology.

With large-scale use of renewable energy sources, the distributed power generation system closer to the load side will also be rapidly developing, based on electricity generation by renewable sources or micro turbines and supported by power storage technology. Distributed power technology has been used in important loads such as airports, hospitals, banks and so on, due to the formation of independent micro-grids, and it could be used as standby power for important users or in remote areas. Micro-grids could be interconnected with large networks, in order to achieve combining operation of power generation by renewable energy. Clearance and instability are the most prominent negative factors for combined network and power generation by renewable energy. How to attemper, monitor, control the power quality of large grids, and develop energy-storing technologies with large-capacity, long-life and cost-effectiveness, are all key technical barriers for China to overcome, if we are going to build large-scale renewable energy base for power generation, and increase the proportion of renewable energy need. After all, it is an important direction of development of energy technologies.

(4) Large-scale Using Technology of Renewable Energy

At present, large-scale industrialization has been realized in hydroelectric power and accounts for 16% in the global power structure; wind power generation, solar energy power generation industry have been developing rapidly, that the global annual growth rate of installed capacity is about 40%; as an important supplementary and alternative source of fossil fuels in the future, the technological and industrial development of biomass fuels and biomass power generation are also very fast. The use of renewable energy is a major energy development strategy in China, but a series of key technologies need to be addressed urgently.

As for wind power generation, in the near future, it is necessary to greatly strengthen the research on the MW-class WTGS, and realize large-scale domestically-produced WTGS; investigate carefully on resources, to provide resources support for building large-scale land-based wind power, and wind farms in offing; to enhance the wind power access system, and R&D of wind power technology in offing and atrocious climatic environment.

As for solar power generation, it is necessary to actively develop a low price, new solar cell. In solar thermal electric power generation, we need to resolve a series of scientific and technical issues including focusing, tracking, conversion, energy storage, and efficiently cooperating with other power generation means. At the same time, we are going to be actively engaged in space power generation, solar thermal power generation, while solving involved technical issues of the grid combining and energy storage.

Biomass energy is the only renewable energy capable of producing gas, solid and liquid fuels, and it can be used in heat utilization, power generation and bio-chemical industry. The key to its large-scale development is to stably provide large-scale biomass energy resources, breed water-saving and appropriate species of energy plants in the desert soil saline-alkali soil, form large-scale industrial base for energy plants. We need to enhance the R&D of the converting technology of algae biomass, and also strengthen the production, research and development of cellulose liquid fuels and bio-enzyme, catalysts and techniques of a large amount of chemicals.

Ocean energy has been enormously stored. But ocean energy density is low. Its energy features are more obvious than other renewable energy sources. To develop it under the complex ocean environment, we also need to address the energy-converting devices, corruption-proof materials, marine power transmission and other key issues.

The developing and using technology of water-based geothermal resources in the surface of the earth has matured, for example, the geothermal power generation, the ground source heat pump, and the geothermal cascade utilization. About the development and utilization of geothermal energy existed in the deeper earth, most recently, the international community have paid close attention to strengthening the geothermal system, and many countries are positively testing on enhancing the assessment of geothermal resources, drilling, reservoir design and inspiration, as well as the technology of converting thermal energy into electricity, and they have made continuous improvement. In the long term, enhanced geothermal resources based on the use of dry-hot rock have great potential. China needs to strengthen the evaluation of enhanced geothermal resources and tests and studies in locale, actively deploy the development of the earth's deep-seated geothermal resources, and eventually achieve a meaningful breakthrough in the expansion of the potential of China's renewable energy resource.

(5) Independent Innovation in the Technology of Nuclear Power and Nuclear Waste Disposal

In order to greatly increase the power installed capacity, ensure energy security, and reduce greenhouse gas emissions, China is planning to significantly develop nuclear power. By 2020, China's nuclear power installed capacity will accounts for about 5% of the national total power installed capacity. Although China is one of a few countries that have a relatively complete system of nuclear industry, but our core technology and equipment still rely on imports.

In order to improve our independent innovation of nuclear energy use, secure our technology and systems, it is necessary for us to explore the large-scale development of nuclear fission energy, ways of nuclear waste disposal and related scientific problems: on one hand, we should pursue active development for enhancing the safety, cost-effectiveness and minimum nuclear waste of nuclear power plants as the main objectives of "the fourth generation" nuclear technology, improve and enhance the nuclear energy system of thermal reactors, develop the nuclear energy system of fast reactors and its closed fuel cycle technology, and optimize the use of uranium resources; on the other hand, we should develop the disposal technology of highly radioactive nuclear waste, improve the technology of sub-actinide nuclides and burning (evolution) long-lived fission products, and achieve a minimum of nuclear waste.

(6) The Basic Theory and Technical Means of the Use of New Energy Sources

It takes decades for energy technology to develop from R&D, breakthrough, mature, to application. If we expect the development of energy technologies in the next 30 to 50 years, hydrogen energy, natural gas hydrates, and nuclear fusion are all important technologies that are likely to affect future energy development. The R&D of these new energies is also an important part of China's energy technology system. However, the development and utilization of science and technology are still in the phase of basic research or technical study, some resources assessment and mining methods have yet to be broken through, so their large-scale development and utilization is estimated to be realized after 2030.

Being considered to be the bridge that connects the era of fossil energy and the future of renewable energy or nuclear energy, hydrogen energy is becoming the vital part of energy strategy and technology competition. Large-scale application of hydrogen energy technology must break through some key scientific problems including the size of hydrogen energy, pollution-free preparation, transportation and high-density storage.

The basis for developing nuclear fusion energy includes fusion physics, fusion technology and other basic researches. The nuclear fusion study has lasted more than half a century, through the two main channels of magnetic confinement and inertial confinement. Nowadays it has met ignition requirements in the laboratory, and the international fusion test reactor ITER is in jointly constructing. China has laid favorable foundation in nuclear fusion research. We insist on combining self-development with international cooperation, actively explore the fusion reactor technology, fully master fusion test reactor technology through participating in ITER construction and operation, adhere to hybrid reactors with China's characteristics, promote the fission development, and eventually realize the operation of pure fusion demonstration reactor around 2050.

As a clean alternative energy, natural gas hydrates has many advantages such as huge reserves, high energy density, widely distribution and can be cleanly used. Studies show that natural gas hydrate reserves of the world is about two times of the total carbon of the earth's existing fossil fuels (oil, gas and coal). In recent years, China has accelerated the deployment in the technology R&D of gas hydrate, started investigations, evaluations, explorations and indoor simulative mining of hydrate resources, and successfully obtained natural gas hydrate samples in the South China Sea. In order to be allowed to implement the demonstrating or commercial exploitation as soon as possible, there is an urgent need for us to establish major scientific device platforms for simulating studies, which could be used to evaluate resources, simulation mining, and solve the problems in exploration, exploitation, storage, transportation and utilization.

ITER Scheme and Actions of China

In 1985, as one sign of the end of the cold war, Soviet Union leader Gorbachev and the U.S. president Regan proposed in Geneva summit "ITER" plan jointly launched by the U.S., Soviet Union, EU and Japan. The purpose of the ITER is to build a self-combustible nuclear fusion experimental reactor, so that we can do further research on nuclear demonstration, commercial nuclear fusion experimental reactors and its physical as well as technical problems.

At first, the U.S., Russia, Europe and Japan cooperated with each other in this project, independent of IAEA, and located the headquarters in the U.S., Japan and Europe. The science and technology condition at that time was far from maturity and the scientists from the four parties proposed a unreasonable ITER design which required an investment of over 10 billion US dollars. In 1998, owing to political reasons and domestic dispute, the U.S. announced its exit from the plan in the name of strengthening fundamental research. The remaining three persisted in their corporation, and amended the design of the experimental reactors to a great extent on the basis of the new development of nuclear fusion research and other hi-and-new-tech developed in the 1990s. In 2001, Europe, Japan and Russia jointly completed the EDA of ITER device and the research on its key components which had an estimated establishment cost of 5 billion US dollars (at its value in 1998). Taking 8-10 years to build, it can operate for 20 years. The independent examination team organized by the three parties respectively all agreed that the design is reasonable and thus acceptable in general.

In 2002, Europe, Japan and Russia negotiated over ITER international agreement and the construction of related organizations on the basis of EDA. China joined the negotiation at the beginning of January, 2003. The U.S. president Bush announced to rejoin the ITER agreement at the end of January, and Korea was accepted to join the negotiation in 2005. Those six parties signed the agreement in June, 2005. They reached common consensus to build ITER at French Nuclear Technology Research Center—Cadarache. India joined ITER agreement in 2006. Finally, seven member governments signed ITER international agreement in October 21st, 2006.

ITER with a Tokamak approach is on the construction pipeline, which marks the fundamental research of the international fusion energy has stepped into the demonstration reactor stage.

ITER project is one of the largest and most far-reaching international R&D cooperation projects. Its construction will take about ten years and five billion US dollars(1998 value).The seven members of ITER is EU, China, Korea, Russia, Japan, India and USA. In order to build ITER, members negotiate with each other to establish a independent international organization, and the leaders have made formal proposals about ITER Plan in different ways in past few years. These are unprecedented in the history of international science and technology cooperation, and fully highlight the attention to the Plan by governments and technological circle. ITER equipments are large-scale nuclear establishment; many technologies have been over the technological standards and norms of thermal reactors. Parties like EU members, USA and Japan that participated in ITER Plan earlier have taken 16 years and 1.5 billion US dollars to pre-research parts, solving most issues of design technologies, manufacture technologies, production techniques and others. They showed their technological strength and implemented their standard systems in the whole design of ITER. ITER devices are made up of several systems and parts, forming 22 purchase packages and 97 purchase subpackages, and the production mission is shouldered by the seven parties respectively.

The overall and every component of the ITER device project might change and have problems in the long time process of 500,000 kilowatts fusion power. The researches on this issue will not only verify the feasibility of the project of controlled thermonuclear fusion, but also provide essential information on how to design and build fusion reactor. The construction, operation and experimental research of ITER are necessary steps of the fusion development that might directly decide the design and construction of the real DEMO, and in the regard, realize the commercial use of fusion power station quickly.

3.2 The Key Technological Directions of China’s Energy Development

There have been three technological revolutions in the human history. The first one is the industrial revolution marked by the invention and use of the steam engine. The second one is the heavy industrial revolution marked by the invention of electricity and large-scale use of fossil energy. The third one is the information revolution marked by the development of the computer and other high-techs. These three revolutions met the material needs brought about by population growth through the development of productivity due to technological innovation. At present, in the era of high oil prices, we are offered unprecedented opportunities for new energy and R&D of new technologies for energy. Particularly to China, only by strengthening the independent innovation in the field of energy could we have a chance to break through the bottleneck of energy and get rid of being controlled by others.

To “promote independent innovation, establish an innovation-oriented country” and assure China’s energy security, considering the resources, contribution, environmental and technical (self-innovation) issues, implementation and economic factors, we have established the following long-term focus on the development of energy technology based on the analyzing key issues of scientific and technological development of China's energy and the current status of domestic and foreign scientific and technological development. We hope that we could gradually form a new energy industry with Chinese characteristics in 2020 by orderly deployment, sustained efforts, aiming at the scientific forefront and forming independent innovation systems of core technologies(Table 3.2).

Table 3.2 Important technological directions of future energy

Sorts	Major technological directions
Energy conservation	• The efficient non-fossil fuels ground transportation technology
Fossil energy	• The clean and high-added value technology of coal
Electricity	• The technology of securing and stabilizing power network
Renewable energy	• The technology of biomass liquid fuels and raw materials • The large-scale generation technology from renewable energy(the photovoltaic cell technology, the solar energy photovoltaic generating technology, the technology of wind power generation) • The engineered technology of deep-seated terrestrial heat
Nuclear energy	• The new technology of nuclear power and disposing nuclear waste
New energy	• The technology of developing and using natural gas hydrates • The technology of using hydrogen energy • Energy technologies with full potentials(ocean energy power generation, new solar cell, the technology of nuclear fusion)

In this study, choices of major directions of energy technologies are based on the following judgments and interrelation.

Firstly, to develop efficient non-fossil fuels ground transportation, mitigate and partially solve problems of China's increasing dependence on foreign oil and inadequate supply, and reduce environmental pollution caused by energy consumption in transportation.

Secondly, to increase the clean and high added-value level of fossil energy, especially for coal.

Thirdly, to pursue breakthroughs in high-capacity, low-loss power transmission technology to ensure the safety of China's long-distance transmission of electricity, to solve the scattered, unstable power generation and transmission technology which could ensure security and stability of renewable energy and set up a "bridge" for large-scale development and utilization of renewable power.

Fourthly, to develop the technology of renewable energy replacing electricity and oil. On one hand, we could promote technological breakthroughs and large-scale commercial applications of the technology of biomass liquid fuel and bio-based raw materials, the technology of solar power generation, the technology of cost-effective and highly reliable WTGS, and biomass power generation. On the other hand, we could pre-deploy the engineered technology of deep-seated terrestrial heat, the technology of new-conceptive solar power generation, the technology of ocean energy independent power system and other energy technologies full of potential, and strive for advantages in the new round of energy science and technology competition.

Fifthly, to accelerate China's scientific research and technological development of the development and utilization of gas hydrates, be better prepared for technical reserves for China's follow-up energy development and utilization; to research and develop the technology of preparing, storing and using hydrogen energy, with the intention of cleaning and using high added-value fossil energy, and cultivating a new type of secondary energy which could connect fossil energy to renewable energy.

Sixthly, to strengthen the R&D of new nuclear power technology and nuclear waste disposal technology, address the problem of the final disposal of high-radioactive waste in spent fuel from nuclear power plants, significantly increase nuclear power installed capacity, upgrade China's technological use of nuclear energy, and promote the formation of national nuclear equipment industry; to actively participate in ITER construction, and digest, absorb, grasp and innovate the key technology of fusion reactor through a combination of self-development and international cooperation.

4 Roadmap of China's Important Energy Technology Development to 2050

4.1 The Highly-efficient Non-fossil-fuel Ground Transportation Technology

4.1.1 Overview

Judging from both technology development route and the serious energy and environment issues, the revolutionary change of vehicles happens at its right time. Electric vehicles, new type rail transportation and full electric power propulsion vessels should be developed to realize the new-generation transportation system which is characterized as fuel-saving and ultimately using the alternative fuel. Developing energy-saving vehicles, electric drive and reducing emissions are the major impetus for the development of China's transportation energy technology.

From steam locomotives to diesel locomotives, from the later adhesion drive transport means like electric locomotives to the current non-adhesion drive transport means like magnetically levitated trains, many revolutionary developments have been achieved in rail transportation system. With the characters of speediness, high capacity and energy saving, rail transportation is the best solution for traffic jam and can meet the demand of quickness.

Fuel cell system is the vehicle engine system that has high potential in efficiency. Fuel cell is a long-term solution for vehicle power system. Hybrid power system, which has both engine power system and electric drive system of traditional vehicles, is a transition plan to the electric vehicle.

The electric vehicle not only has the characteristics of zero emission and zero pollution of fuel cell vehicles but can also stride over the technology of traditional internal-combustion engine, thus suits China's national situation in electric vehicle development.

4.1.2 Key Science and Technology Issues

To realize the development of the highly-efficient non-fossil-fuel ground transportation technology, a series key technologies must be firstly developed: power electronics technology and its system integration technology; motor integrated driving system technology which has high performance, high power density, high reliability, low costs, low pollution, and good environment suitability; hydrogen storage materials and technology, hydrogen integrating technology; fuel cell technology; technology of manufacturing high-energy and high-power cells, fuel cell recycling and processing technology; non-adhesion based linear motor drive technology.

4.1.3 Science and Technology Objectives at Different Time Nodes

From 2008 to 2020: China will develop modularized highly integrated power converters and power electronic control units that meet the demands of various electric machines and the load demand, aiming at developing carborundum as the major power device; at the same time, R&D will be carried out on new types of light capacitance (like ceramic capacitor) of high temperature, high pressure in order to replace the present ponderous electrolytic capacitance; "vehicle-level" high power cell products will be manufactured through the technological breakthrough of new materials, new technologies, new craftwork and new devices.

R&D is based on high power conversion system and new traction, propulsion, drive system and control system of new devices like IGCT/high voltage IGBT, etc. China strives to realize the objectives that by the year 2020 or so, the common technology of electrified transport means and the hybrid power and electric vehicle technology tend to be mature, that the cell technology, power electronic new material, new device and integration technology, new rail transportation technology, electric vehicle technology will find large-scale commercial application and that in this way there will form integrated technology chain and industry chain of highly-efficient non-fossil-fuel ground transportation technology.

From 2021 to 2035: with the technological development of electric vehicle and fuel cell vehicle, gradual improvement will be focused on the proportion of high efficient and fuel-saving vehicle. By 2035, China shoots for substituting all the traditional vehicle by electric vehicle, reducing the oil consumption of around 0.6 billion tce and CO_2 emission of around 1.2 billion tons.

4.1.4 Science and Technology Development Roadmap

Science and technology development roadmap for the highly-efficient non-fossil-fuel ground transportation technology is shown in Fig.4.1.

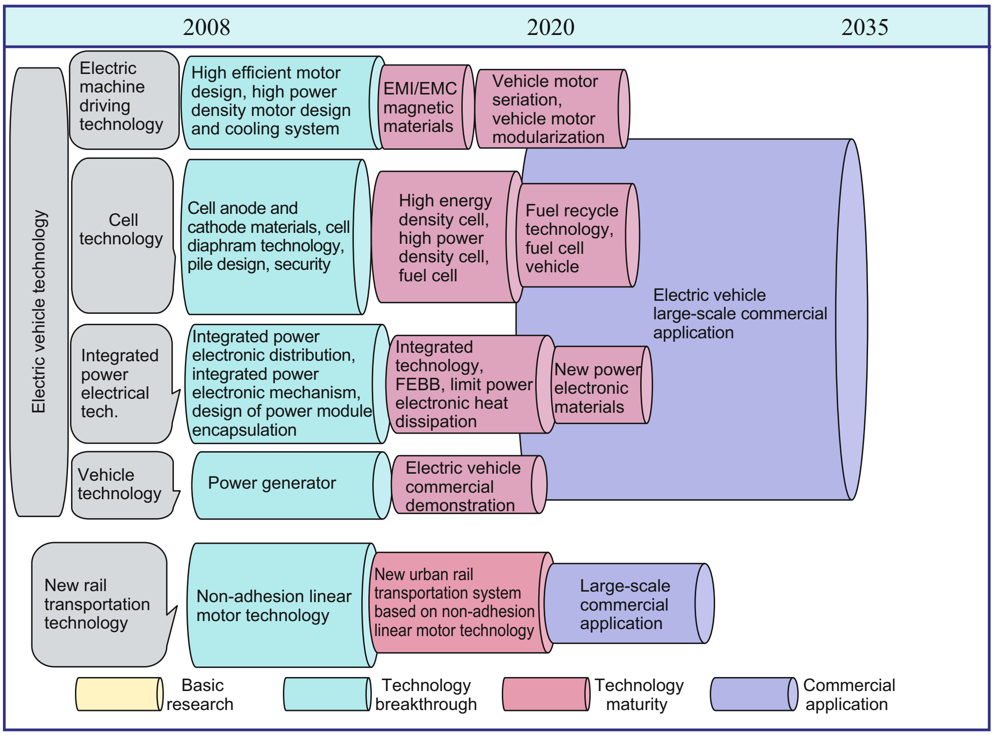


Fig. 4.1 The highly-efficient non-fossil-fuel ground transportation technology roadmap

Types, Principles and Development of Electronic Vehicles

According to the different power sources, electric vehicles can be classified as electric vehicle, hybrid electric vehicle and fuel cell electric vehicle.

Pure Electric Vehicle refers to a battery-powered automotive vehicle that is propelled by rechargeable batteries. However, due to the existing disadvantages of the internal-combustion engine such as high price, short using life, low energy density and long charging time, the current electric vehicle is difficult to be popularized and its development is restricted by the development of battery.

Hybrid Electric Vehicle (HEV), according to the International Electrotechnical Commission (IEC), is defined as: a hybrid vehicle that has more than one energy converter for propulsion. Under the tight strategic control, HEV captures hybrid energy by using appropriate fuel converter (the internal-combustion engine, ICE), energy storage device, electromotor, etc. Under the drive condition, it can enable fuel conversion device, storage device and electric machine working in the region of high efficiency and low emission. Under the braking condition, the HEV can recycle braking energy partially through the regulation of generator or working quadrant of electric machine, and in this way improve fuel economic performance, emission performance and other using performances significantly when driving under different working conditions. HEV aims at reducing both fuel consumption and emission pollution. Combining the advantages of both traditional ICE vehicle and electric vehicle, HEV is not limited by continuous voyage of mileage. It changes a little on the basis of traditional vehicle, and the inputs of its industrialized production are much less compared to the fuel cell vehicle.

Fuel Cell Electric Vehicle (FCV) refers to the automotive vehicle that is paralleled by fuel cell. Fuel cells can use many primary fuels as their source materials such as natural gas, coal gas, methanol, ethanol, gasoline. Some other low-quality fuels which can not be used in power plant like lignite, waste woods, waste paper and even city waste can also be considered as a source material of fuel cells. Fuel cell which is an electric generating device of electrochemistry can directly transform chemistry energy to electric energy isothermally without experiencing heat engine process and this explains why it can enjoy high conversion efficiency (40% to 60%) and get rid of the Carnot cycle.

In the recent 20 years, industrialized countries considered the R&D of electric vehicle as an effective way to solve environment and energy problem, and thus invested a lot of money on it. Vehicle manufacturers also chose to develop electric vehicle in future. Large overseas vehicle firms have already produced hundreds types of electric vehicles, fuel electric vehicles and hybrid electric vehicles. China's vehicle firms also attach importance to electric vehicle. Almost all the domestic vehicle firms such as FAW, Saic Motor, Dongfeng Motor Corporation, Chang'an, Chery, BYD, Geely all hugely invest on projects of R&D and commercial attempt of electric vehicle.

Electric vehicle has been used in special areas. Its technology has become mature and has been widely popularized for commercial application in America, Japan and Europe. It now begins to step into practical stage, but still mostly used in special areas like public transportation system because of the current restriction of cell technology and cost. At present, there are about 40,000 electric vehicles over the world, including 8,000 in France, 7,000 in America and 7,400 in Japan. China has also launched many electric vehicles such as the Happy Messenger and many other types from Tianjin Qingyuan Electric Vehicle Co., Ltd., the Cross Over from BYD, Chery S18, etc.

Source: Ronggui Zhang, 2008. The prospect of electronic vehicles in China. Mechanical and Electrical Technology, 4(31):81-84

4.2 The Clean and High-added-value Coal Utilization Technology

4.2.1 Overview

Coal is the most important basic energy resource in China. As far as it can be foreseen, coal will be China's major energy resource in quite a long time. Coal has contributed a lot for the country's economic development, but in the process of development and utilization, coal generates dust, coom, SO_2, NO_x, and leads to serious environment pollution. Therefore, the biggest restriction for coal utilization is the application of advanced technology and the control of environment pollution.

4.2.2 Key Science and Technology Issues

The clean of coal and high-added-value utilization aim at realizing high efficient conversion of coal, clean coal chemical industry, low emission utilization and the efficient utilization of low rank coal. The major technique issues include: purification techniques of high temperature resistant material and gas in the technology of adjustable carbon hydrogen ratio; catalytic combustion and reaction control in the burning technique of new clean coal; directional transfer control of product in the process of chemical conversion of coal; the process design and technique integration of the combination and utilization between coal and renewable energy resources; the catch and storage of CO_2.

4.2.3 Science and Technology Objectives at Different Time Nodes

From 2008 to 2020: build the gasification model and technique process of all kinds of materials and adjustable carbon hydrogen ratio, solve the technical problems on high temperature resistant materials, high temperature gasification and process control; basically build advanced burning theory and techniques like pure oxygen burning and chemical radical burning, and overcome the problem of related materials and process control; resolve the problem of catalyze design of coal chemical industry and process control; build the theory system, technique model and application and demonstration system of integrating and utilizing coal and renewable energy resources; break through the catch and storage technology of CO_2. Around 2020, China strives to realize the large-scale commercial application of most clean coal technologies. The high efficient electric generating technology which based on the advanced burning technology will also become mature and the catch and storage technology of CO_2 will tend to be mature and will be put into large-scale commercial application.

From 2021 to 2035: all the technologies of the clean of coal and high-added—value utilization will be put into large-scale commercial application. China will reduce the speed of the increasing utilization of coal and finally realize zero increase or negative increase by phasing out the traditional technology device.

The contribution of large carbon hydrogen ratio adjustable gasification and green transformation technology is predicted to take up over 50% of the technology of coal resources, the contribution of new coal burning and electric generation technique is predicted to take up over 80% of the electricity generation technology by coal, and ensure that coal will be clean and high-added-value used.

4.2.4 Science and Technology Development Roadmap

Science and technology development roadmap for the clean and high-added-value coal utilization technology is shown in Fig.4.2.

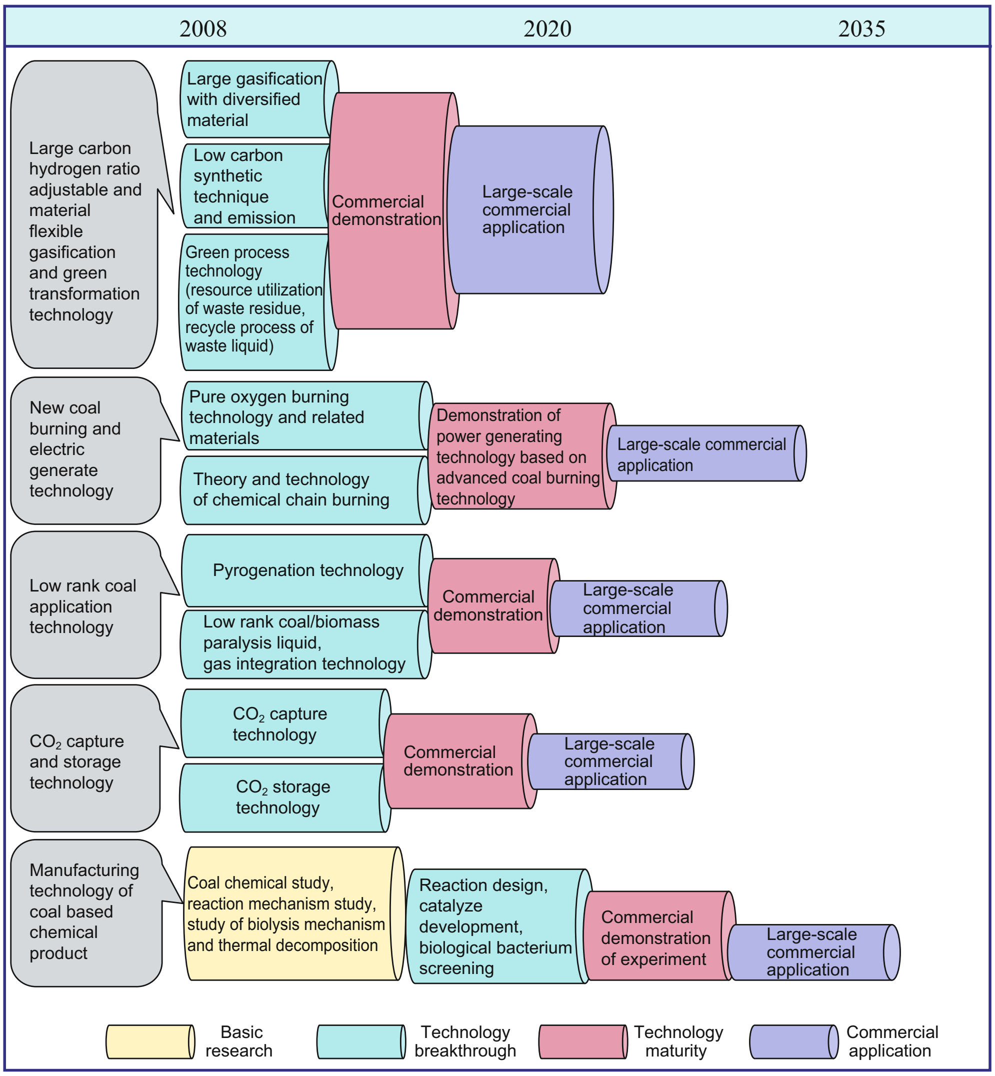


Fig. 4.2 The clean and high-added-value coal utilization technology roadmap

4.3 The Power System Security and Stability Technology

4.3.1 Overview

It is a technology system for the supporting technology to be responsible for improving the long-distance transmission capacity and ensuring the stable operation of power grids. It consists of power electronic devices with new materials, real-time perception, detection and data transmission of power system operation as well as all-digital real-time simulation system, EHV, UHV transmission technology for supporting the above intentions, FACTS technology, large-scale power equipment cooling technology, superconducting power technology, etc. Besides, because renewable energy generation capacity devices are scattered, China needs to develop coupling technology combining large power grids in order to ensure the renewable energy's stability and security, and also develop distributed power based on advanced energy storage and micro-grid technology.

Taking the power system which includes electricity generation, transmission, distribution and consumption as object, China will constantly develop new power grid control technology, information technology and management techniques, then all of them will be integrated organically to realize intelligent exchange of information from all the aspects in the power system. The power production, transmission and utilization will be optimized systematically, and we will build an intelligent power grid system featured with "security, automated response, economy and clean". It will provide high-quality electric power and services which will meet the need of socio-economic development, and they are the main future objects of power grids' technology development in terms of security and stability.

Superconducting Power Technology

Superconductors are a kind of new materials found in the early 20th century. Their most important characteristic is zero DC resistant at low temperatures, which is known as the "superconducting state". Besides zero DC resistance, superconductors have unique physical properties such as the "Meissner effect", at which the internal magnetic fields become zero, and the "quantum tunneling" effects. Utilizing these three properties, a wide range of future applications can be realized. When the superconductors are carrying DC below certain critical current, there is no resistance loss. Even if the superconductors are carrying alternating current or in an alternating electromagnetic field, their loss is generally 2 to 3 orders of magnitude lower than that of good conductors. This makes the superconductors an ideal carrier material in various types of electronic and electrical appliances. Further more, since superconductors have significant resistance changes in the transition process from the superconducting state to the normal state, they can be used as fault current limiter, superconducting switches, and applied in many other occasions, such as superconducting computers.

Superconducting power technology is a cutting-edge technology which means the superconductors are applied in the field of power engineering. It is an applied technology developed by using of superconductors' zero resistance and high density current-carrying capacity as well as their unique physical properties generated from the transition from the superconducting state to the normal state, and it is also a new technology which will bring revolutionary changes to the power technology in the future.

As high-tech reserve of electric power industry, the superconducting power technology refers to multidisciplinary cross-integration including superconductor material science, superconducting physics, cryogenics and refrigeration technology, power electronics, power system, automatic control, etc. Superconducting power technology can overcome the inherent shortcomings of the conventional power technology and fundamentally improve the power quality and the stability and reliability of power system operation, lower voltage levels, improve the power grids' security, enhance the unit capacity and power grid transmission capacity, reduce the loss of power grids, and ultimately resolve the bottleneck problem in the development of the electric power industry. In recent years, the main development interests of superconducting power technology include superconducting current limiter, superconducting power cables, superconducting transformers, superconducting magnetic energy storage system, superconducting motor as well as FACTS based on superconducting magnet technology. At present, superconducting power technology is on the experimental operation stage, and the small low-temperature superconducting magnetic energy storage system has been commercialized.

4.3.2 Key Science and Technology Issues

1) Flexible AC transmission (FACTS) technology: it can improve the system stability and the capacity of long-distance transmission. It means that less transmission lines need to be built and the efficiency of current lines and equipments can be improved.

2) All-digital real-time simulation technology of power system: the primary element model of all-digital real-time simulation system only depends on the software instead of the hardware, and it provides adequate space for development in terms of new components simulation for the users.

3) Real-time detection technology of power system: sensing technology puts monitoring equipments in the power grid and makes the perception a part of the equipment; communication technology transfers perception data to central control point; integration technology puts the collected data into the public database; centralized control technology makes use of data to carry out monitoring and controlling; the enhanced system scheduler activates the ability of enhanced system to analyze data and achieve full automation and optimization.

4) Superconducting power technology: focuses itself on problem resolving in preparation of new superconducting materials, large-capacity superconducting magnet technology, on-line measurement and control technology, cryogenics and refrigeration technology. To explore and prepare new high-temperature superconducting materials with high-performance and low-cost is very important to promote application of superconducting power

technology. Superconducting magnet is the key component of superconducting power application, its main problems to be resolved are thermal stability, low-temperature high-voltage insulation, high-current and rapid charging-discharging of the superconducting magnets. The electromagnetic transient characteristics of superconducting power devices differ greatly from conventional electrical devices, thus it is extremely important to research and explore the correlations between the electromagnetic transient characteristics of superconducting power devices and the stability of the power grid. Finally, it is also of great importance to solve the basic theoretical problems of the power system with superconducting power devices and that of the superconducting power system.

5) Common technologies of stable and secure power generation and transmission of renewable energy: the first one is about power grid coupling and power quality. Considering China's renewable energy resources and power grid characteristics, in-depth study should be carried out on distributed power generation and combined grid planning theories, standards and statutes, and also actively develop devices used for power generation and combined grid with independent intellectual property rights. The second one is about distributed intelligent power distribution grid. With the backbone of micro-grid, distributed intelligent power distribution grid is recognized as an important part in hierarchical distributed power system in the future. The concept of distributed intelligent power distribution grid has just been introduced into China, and it is needed to establish relevant theoretical system and norms. At the same time, to achieve the purpose of low loss, high reliability, high energy efficiency and low-cost clean electricity, China must strength the research and development towards distributed power, smart appliances, distributed intelligent controller, intelligent relay protection, etc., and form a new generation of distribution grid forms of organization and operation with the core of a micro-grid to realize digital and intelligent grid. The third one is about energy storage technology which applies to distributed power generation. Energy storage is an important component of distributed power. Research and development are needed for large-capacity, low-cost energy storage materials, processes, technologies and equipments so as to complete energy storage with high-power density, high-energy density and long service life. Improvements on the stability and power quality of distributed power generation system itself as well as bulk grid should be realized. At the same time, adjustment on the energy match and peak shaving between power generation and load can be achieved.

4.3.3 Science and Technology Objectives at Different Time Nodes

From 2008 to 2020: the industrialization of high-voltage silicon-based devices; the production of carborundum devices; the localization and standardization of high-capacity, high-voltage power electronic devices based on the devices introduced from abroad; superconducting power technology will achieve small-scale applications to power distribution system, breakthrough will be made in the research of key science and technology in the application of superconducting power technology to the power transmission system and in its practical utilization; distributed power generation technology will gradually be mature and achieve large-scale development; we will form the micro-power grid theoretical system and standards and achieve multimode demonstration; key technological breakthroughs in terms of energy storage and form scale demonstration in the micro-grid and power system will be made; the key technological breakthroughs and demonstration will provide technical basis for the establishment of smart power grids.

From 2021 to 2035: the industrialization of carborundum devices; the production of new silicon-based devices; the standardization of high-capacity power electronic devices based on domestic silicon-based devices; the application of superconducting power technology in the power system will be further developed and promoted, and gradually become the key technology in the power system; realizing intelligent and commercial micro-grid, establishing theoretical system of distributed intelligent power distribution grid and achieving local demonstration; the energy storage will become more practical and large-scale operation of flexible power and peak shaving will be realized.

From 2036 to 2050: the industrialization of deflectors based on carborundum devices; the application of diamond devices; the standardization and industrialization of power electronic devices based on domestic carborundum devices; the completion of large-scale real-time simulation system; the key technology and equipments of distributed intelligent power distribution grid will basically be mature and the electricity trading system of regional distribution grid based on micro-grids will realize wide range of grid operation; the energy storage will become an important fulcrum of reliability and stability towards power system.

Through continuous technological breakthroughs, security technologies of power equipments and new technologies of power grid security will gradually take the place of traditional electrical security technologies. The proportion of security technologies of power equipments and new technologies of power grid security will reach 50%, 70% and 90% by the year 2020, 2035, and 2050 respectively. A smart grid system will be built in China step by step to reduce line loss rate and improve the efficiency of overall energy. In power system, superconducting power devices will get multi-level and large-scale application and the theoretical system for superconducting power system will be established and perfected. The contribution of the advanced superconducting power technology will account for 40% in the power grid by 2050.

4.3.4 Science and Technology Development Roadmap

Science and technology development roadmap for the power system security and stability technology is shown in Fig.4.3.

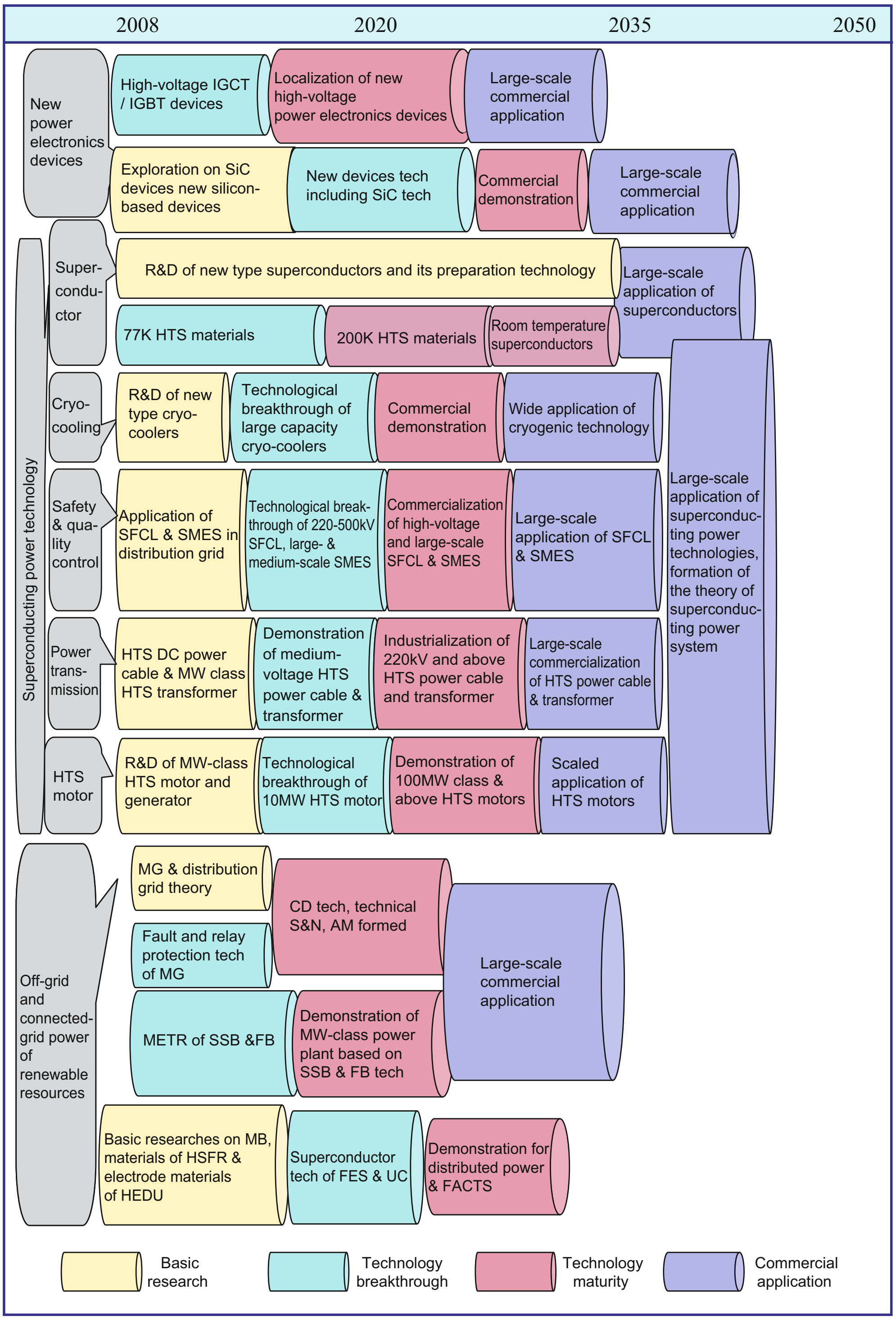


Fig. 4.3 The power system security and stability technology roadmap
(MG, Macro Grid; S&N, Standards & Norms; AM, Advanced Management; METR, Materials, Electrolytes, Technologies, Reliabilities)

Advanced Energy Storage Technologies

Energy storage has played an important role in economical and efficient operation of power system, power quality improvement, new energy generation as well as electrified transportation, etc. According to different application areas, capacity demand for energy storage ranges from tens of kilowatt to hundreds of gigawatt, and supporting time could range from milliseconds to hours.

In accordance with the working mechanism, energy storage can be classified as 4 categories: ① mechanical energy storage(such as pumped storage, compressed air energy storage, flywheel energy storage, etc.); ② chemical energy storage(such as sodium sulfur batteries, flow batteries, lead-acid batteries, lithium batteries, nickel cadmium battery, etc.); ③ electromagnetic energy storage (such as superconducting magnetic energy storage, supercapacitors, etc.); ④ phase change energy storage (ice storage, etc.).

Energy storage is important to stability improvement of grid operation, power quality improvement, and peak load shifting, especially when distributed generation, based on highly efficient and cleanly use of renewable energy or fossil energy with high penetration. The combination of power storage and demand side management would provide an effective solution to the regulation of the peak-valley difference of power system load. Over a long period of time, a large amount of manpower and material resources in the areas of energy, power system and materials have been spent to develop a variety of energy storage technologies mentioned above. According to its energy and power characteristics, these energy storage technologies have done demonstration applications in the improvement of grid stability, power quality, and peak shaving. However, to promote applications of energy storage technologies, we still have problems such as cost, efficiency, environment, geographic location, and many other problems, among which the issue of cost is the biggest obstacle. A large number of centralized and distributed renewable energy generations and distributed generations based on the efficient use of clean fossil energy, will have access to grid in the future, so that low-cost, high-efficiency energy storage technologies will be essential for grid technologies required in the future. According to current research and development status of advanced energy storage technologies, sodium sulfur cells and flow batteries being large-capacity power storage technologies combined with renewable energy generation could enjoy good prospects of development and applications, and superconducting, flywheel and super capacitors are of great value to solve issues about grid operation stability and power quality.

Source: Eyer J M, Iannucci J J, Corey G P. 2004. Energy storage benefits and market analysis handbook: a study for the DOE energy storage systems program. SANDIA REPORT, SAND2004–6177, Sandia National Laboratories

4.4 The Biomass Liquid Fuel and Raw Material Technology

4.4.1 Overview

Biomass has always been one of the energy resources in human society. With its characteristics of clean and multi-functional, it is the only renewable energy resource that can be developed into a diversity of high-level energy resources including solid, liquid, gaseous and electrical fuel. After all these years of development, China's skills on exploiting and utilizing biomass have become increasingly diversified. In accordance with the needs of solving bottleneck problems of energy resources, biomass liquid fuel and raw material technology will be the important method to take place of crude oil in the future. The biomass liquid fuel and raw material technology system includes various technologies such as biomass-to-liquid fuel conversion, industrial plant, plant breeding, advanced industrialization of biomass, etc.

4.4.2 Key Science and Technology Issues

(1) The Selection and Cultivation of Energy Plant

Through the approach of bio-technology and modern breeding, high energy-storage plant can be cultivated, and the key technical platform for large-scale energy plant cultivation can be established. The safety evaluation of crops planting in a large scale, its theory as well as the model of energy farm, and the standardization of regional planting can also be achieved.

(2) The Selection and Cultivation of Oil-containing Microalgae

The microalgae which has a high fatty acid content, capability of rapid growth and excellent resisting performance, together with the oil-containing organisms which have gone through genetic engineering, will be sorted out. With a breakthrough in developing the technology of cultivating oil-containing algae as a fuel, the large scale production technology consisting bioreactors as its core as well as intellectualized greenhouse can be established, and highly-efficient technology in producing liquid fuel from oil-containing algae and that of raw materials can also be improved.

The Technology of Exploiting Oil-containing Algae

Microalgae is one of the world's most widespread unicellular organisms with the fastest rate of proliferation. Existing in unicellular, filamentous or prothallial forms, microalgae has a simple structure, and is thus capable of carrying out photosynthesis throughout the whole organism, having a very high efficiency. To be viewed as an important renewable energy, it also has the advantage of a short and fast life-span. Microalgae has very high oil content. For instance, some pulverized dried algae has oil content much higher than common oil crops, amounting to 40% to 60% and at most 80% of the cell's dry mass. The utilization of microalgae as energy resource is also wise in the sense that it will not occupy land capable of planting crops and trees. Therefore, it is regarded as a strategic resource in the development of biofuel. Furthermore, Algae also has a high content of bioactive substances such as protein, vitamins, and carbohydrates, so it can be used in other ways after oil-extraction, including the production of fine chemical and forage additives. These multi-functions prove that microalgae is a biofuel of high potential. Owing to such a fact, the technology of exploiting oil-containing microalgae is a long-term project, to which well-planning and approach selection are to be attached with great importance.

The foundation of the conversion from microalgae to biofuel is certainly microalgae, but the key lies in the photoreactions. In the exploitation of microalgae, two processes are in the pipeline: the selection of highly-efficient species of microalgae, and the cultivation of industrial microalgae. Since 1978, the USA had established the R&D project of producing biofuel from algae. Through that project more than 3000 species of algae are extracted from oceans and lakes, among which 300 species having the highest growth rate and oil-content are selected. They are mainly diatom algae, green algae and blue-green algae.

After cultivation, some of the algae reached the photosynthetic rate of 50 $g \cdot m^{-2} \cdot d^{-1}$ and an oil content of 80%. Under identical conditions, the photosynthetic rate of algae is tens of times higher than advanced plants. This is because fatty acid undergoes abnormally vigorous synthesis in algae. With the help of genetic engineering, the regulation of fatty acid in microalgae can be manipulated and the synthetic ability greatly improved, and the aim of producing biofuel from high oil-containing microalgae can hence be achieved. To develop industrial algae and research on the lipid synthesis relating acetyl-coenzyme A carboxylase (ACCase) is to realize a highly effective expression of ACC in microalgal cells.

Experiment results show that the lipid metabolism relating phosphoenolpyruvate carboxylase (PEPC), after ACCase methylglyoxal synthesis, can catalyze the entry of the substrate acetyl-coenzyme A into the synthetic pathway of fatty acid; a high concentration of acetyl-coenzyme A can activate PEPC, and hence catalyze the entry of phosphoenolpyruvate, oxalic acid and acetic acid into the synthetic pathway of amino acids. Inhibit the activities of PEPC will accelerate the entry of substrate into the fatty acid pathway with the help of ACCase. The currently undergoing R&D focus mainly on how to achieve a breakthrough in accelerating the growth rate of microalgae, realizing large-scale cultivation and improving expressional effectiveness of algal heterogonous gene.

The technology of microalgae-biofuel conversion is approaching its mature stage, but scale and cost are the bottleneck factors hindering its commercialization. Nevertheless, considering from a technological economic perspective and looking forward to the future, efforts should be made persistently in this field for the strong competitive edge, this technology will become more and more obvious as it improves, and the worsening natural environment will demand so. Already the governments and multinational enterprises in Europe, the USA and Japan have invested hugely on R&D of this field. Their focus is mainly on selecting high oil-content microalgae among species living in the ocean and semi-saline water, and then experiment on their regulated cultivation in laboratories. Universities and scientific research institutions in China are also beginning similar research. In February, 2009, Chinese Academy of Sciences and China Petroleum and Chemical Corporation jointly announced the initiation of a project concerning the development of a complete set of technology of microalgae and biofuel, and began cooperating in this field.

Source: ①Spolaore P, Joannis-Cassan C, Duran E, et al. 2006. Commercial applications of microalgae. J Biosci Bioeng, 101: 87–96 ; ② http://www.cas.ac.cn/10000/10001/10000/2009/132771.htm

(3) Energy Conversion Technology Upgrade of Regular Biomass

Intensified fundamental research on industrial plants, aquatic plants, bionics in oil-containing micro-organisms, biochemical reactions, thermal reactions, bio-surfactant and cellulosic biological reaction; enhancement in various technical systems of conversion, including gasitification, cracking, catalysts, hydrolysis, synthesis and the upgrade of biological enzymes.

4.4.3 Science and Technology Objectives at Different Time Nodes

From 2008 to 2020: the key technology of large-scale energy crops cultivation should be well developed and the technical bottleneck in conversion and application of biomass passed; key technologies such as advanced methane fermentation, biofuel, biomass power generation should be commercialized; the R&D of the second generation biomass liquid fuel technology should be in the pipeline.

From 2021 to 2035: energy farms should be established, the key technology and commercial model of biomass liquid fuel should be available; cellulosic ethanol fuel, synthetic biomass liquid fuel, biomass cracking fuel and biomass chemical will be proven to have an evident competitive edge; research on discovering new biomass energy technology should be under progress.

From 2036 to 2050: the second generation of biomass liquid fuel technology should be commercialized; new biomass energy technology, such as hydrogen production from biomass, marine biomass energy, micro-organism fueled cells, oil-containing bio-energy resource, artificial photosynthetic energy conversion system, etc., should be discovered; the third generation of biomass technology demonstration system should be established.

4.4.4 Science and Technology Development Roadmap

Science and technology development roadmap for the biomass liquid fuel and raw material technology is shown in Fig.4.4.

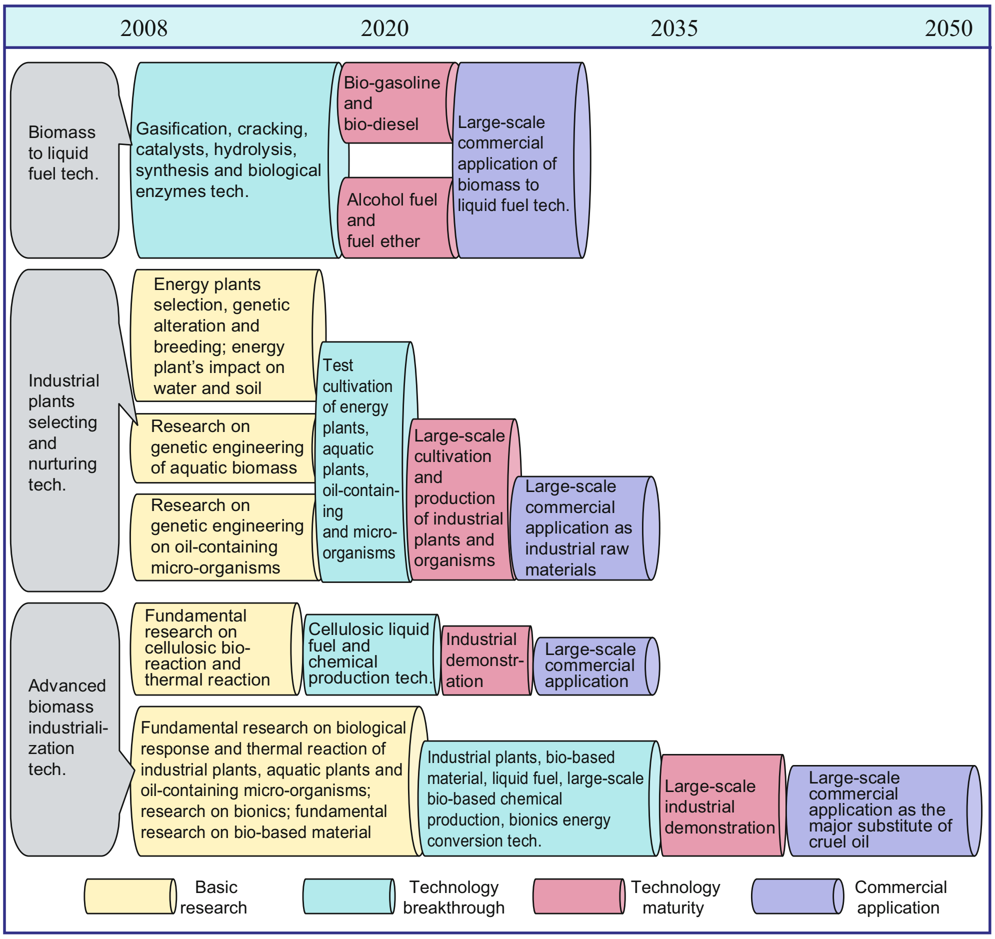


Fig. 4.4 The biomass liquid fuel and raw material technology roadmap

4.5 Large-scale Power Generation Technology from Renewable Energy Resources

4.5.1 Overview

(1) Wind Power

The technological development of wind turbine in China is lagging behind and dependent on foreign institutions. It is now in urgent need of an independent, unique Chinese system of technology to support the R&D of new wind turbine, integral level of design and the enhancement on the quality of the components. China is currently in lack of IPR-possessing converters and controllers, which are the key components in a wind turbine of variable speed and constant frequency at megawatt level. The R&D on the essential technologies of offshore wind power generation and new wind power system are yet to be completed, and national ground experimental testing platform for wind turbines, as well as trial wind power plant yet to be established.

(2) Solar Photovoltaic Power

Solar PV power generation is a process consisting of two main parts: solar cells and PV system. In recent year, the development of solar PV industry has been thriving and productive. In order to ensure a rapid and sustainable development in the photoelectric field, the following groups of problems should be solved in the future. The first group concerns the production technology of solar grade silicon materials. The difficulties in production and related IPR dispute of high energy consuming silicon material are yet to be dealt with, and there is also a more obvious problem that both the source of raw materials and markets of solar cells are not local but foreign. To reduce the cost and increase the efficiency of solar cells, the adaptation of silicon slicing technology, new design of cell structure, solar cells related techniques and supplement facilities are the way out. The second group is about thin film solar cells. The preparation of relevant materials and a breakthrough in large-scale cell production technology are other key issues in R&D of solar PV field. The new, cheaper thin film solar cells are an embodiment of the future direction of such development. The third group is related to PV plants. As an essential step to large-scale application of solar cells, the improved design of various scales of parallel power plant, modularized integration, grid inversion, group control technology and the regulation on relevant standards and design of standardized construction are all important issues in the solar PV field.

(3) Solar Thermal Power

There are three approaches to realize the utilization of solar thermal power, namely solar tower systems, solar trough systems, and solar dish systems. The technology of solar thermal power includes integration of general plants, optics, thermal, material, control, heat transfer, etc. It is a very complicated way of power generation with many separate parts to accomplish. Currently, the solar thermal power generation technology in developed countries are already mature. The cost of key facilities in plants is significantly lowered. In China, the development of such technology is at its initial stage. In terms of general system designs, light concentration, solar thermal conversion, measurement and production of materials and devices, we have achieved much less than the international standard in various aspects including R&D level, extent of utilization and industrialization.

4.5.2 Key Science and Technology Issues

(1) Wind Power

Discover technologies of designing key components in wind turbines; focus on clearing the obstacles in developing controllers and converters; develop an IPR design technology for machines and key components; research and develop the utilization of offshore wind power; establish the experiment platform of wind power simulating and transmission; enhance the demonstration and cultivation of key technologies as well as the fundamental research of wind power; promote the commercialization of wind power.

(2) Solar PV Power

First, improve the efficiency and commercialization level of silicon-based solar cells through the development of highly-efficient silicon-based solar cells, especially the technological breakthrough in the development of silicon-based tandem thin film solar cells; second, develop new, low price solar cells, such as dye-sensitized solar cells, CdTe solar cells, solar concentrator cell and CIGS thin film solar cells, improve their conversion efficiency, develop low-cost solar cell technology and focus on the well stability, practicability and ability to be commercialized of solar cells.

(3) Solar Thermal Power

For solar tower system, develop the technologies of heliostats' design and production, high temperature/corrosion resistant and efficient heat absorber, high temperature heat transfer fluid, extra-large-scale heat storage, integration of general solar thermal plants; for solar trough system, develop the technologies of high-temperature trough-type vacuum pipe and the production of high-accuracy one-dimension heat-strengthen curved-surface reflectors; for the dish type, develop the technology of a dish/stirling system breaking though a rate of 5 to 30 kW in solar thermal power.

4.5.3 Science and Technology Objectives at Different Time Nodes

(1) Wind Power

From 2008 to 2020: research mainly on key components of 3MW wind turbines, realize the commercialization of controlling system, convertor system and wind turbine blades, and establish large-scale public experiment platform for conventional wind turbine system and testing of blades; develop autonomously onshore 5MW wind turbine and its key components, realize the commercialization of controlling system, convertor system and blades of 5MW wind turbine, and extend further the platform of wind turbine testing; develop autonomously offshore 5MW wind turbine and its key components and realize the commercialization of controlling system, convertor system and blades of 5MW wind turbine.

From 2021 to 2035: promote further the large-scale commercial operation of wind power; research autonomously 10MW wind turbine and its key components, realize the commercialization of its controlling system, convertor system and blades.

Around 2050, wind power will overtake water power and be the second major power source. The commercialization of offshore wind turbine, a 12% dominance of wind power in the total electric capacity and an extensive use in other fields will be achieved.

(2) Solar PV Power Generation

In the coming 20 years: focus on the development of silicon-based solar cells, i.e. highly-efficient silicon-based solar cells, especially silicon-based tandem thin film solar cells, and constantly improve new and low-cost solar cells such as dye-sensitized solar cells, CdTe solar cells, solar concentrator cell and CIGS thin film solar cells; as the solar cell technology will be continuously advancing, the installation capacity of PV power generation will increase and the stability in the field of PV parallel system will be enhanced.

From 2008 to 2020: focus on electrification in rural areas, the implementation of BIPV in urban areas and the construction of power plant in deserts; it is hoped that in the year of 2010, PV installation capacity will reach 300MWp, and 1.8 GWp in 2020, and silicon-based solar cells will be in the lead; master related technologies of 10MW PV power plants.

From 2021 to 2035: focus on the large-scale commercialization and application of the thin film solar cell related technologies, determine the direction of low-cost solar cells development suitable for China, master related technologies of 100 MW PV power plant, and achieve a PV installation capacity of 50 GWp.

As the reduction in supply of fossil fuels and increase in their prices as well as the drop of price in thin-film PV technology, the cost of thin film PV cells will be comparable to conventional energy resources. In the year of 2050, PV installation capacity will reach 600 GWp, 5% of the national current power installation capacity. At that time, the objective to master the related technologies of a 1000 MW PV power plant will be achieved.

(3) Solar Thermal Power Generation

From 2008 to 2020: focus on the research of key technologies related to solar thermal power generation, its integration, as well as the systematic integration of the technologies, firstly, establish experimental and demonstrating solar thermal power plant to prove the feasibility of the technology; master autonomous technologies that reach the international technological and economic standard; discover further technologies suitable for China to build large-scale low-cost commercial power plant, and construct demonstrating commercial solar thermal power plant; strive for a breakthrough in the fields of suitable technologies of concentrating solar radiation, heat absorbing, heat transfer and storage, which is the key advanced technologies fuelling the commercialization of solar thermal power; strengthen and perfect the integration of system, establish major projects on solar tower gas-stream circulation technology; realize the commercial demonstration implementation of solar tower, trough and dish power generation at a level of significant demonstration.

From 2021 to 2035: strive for further breakthrough in development of key technologies; at that time, solar thermal power generation should have been proven to be of evident competitive advantages economically; the technologies of highly-efficient gas heat-absorption, latent and chemical heat storage at lower cost, trough DSG(direct stream generation) and solar dish system are approaching to their mature stage, large-scale solar thermal power generation system is commercially implemented; research further on enhancement of solar thermal power technology to support its large-scale implementation.

(4) Objectives of Replacement of Fossil Fuels and Carbon Emission Reduction

Realize the implementation of large-scale power generation using renewable energy. It is estimated that in 2020, 2035, and 2050, wind power and solar power will have a 5%, 10% and 20% share respectively in the total energy consumption. The reduction on CO_2 emission will reach 500, 1600 and 3500 million tons respectively.

4.5.4 Science and Technology Development Roadmap

Science and technology development roadmap for the large-scale power generation technology from renewable energy resources is shown in Fig.4.5.

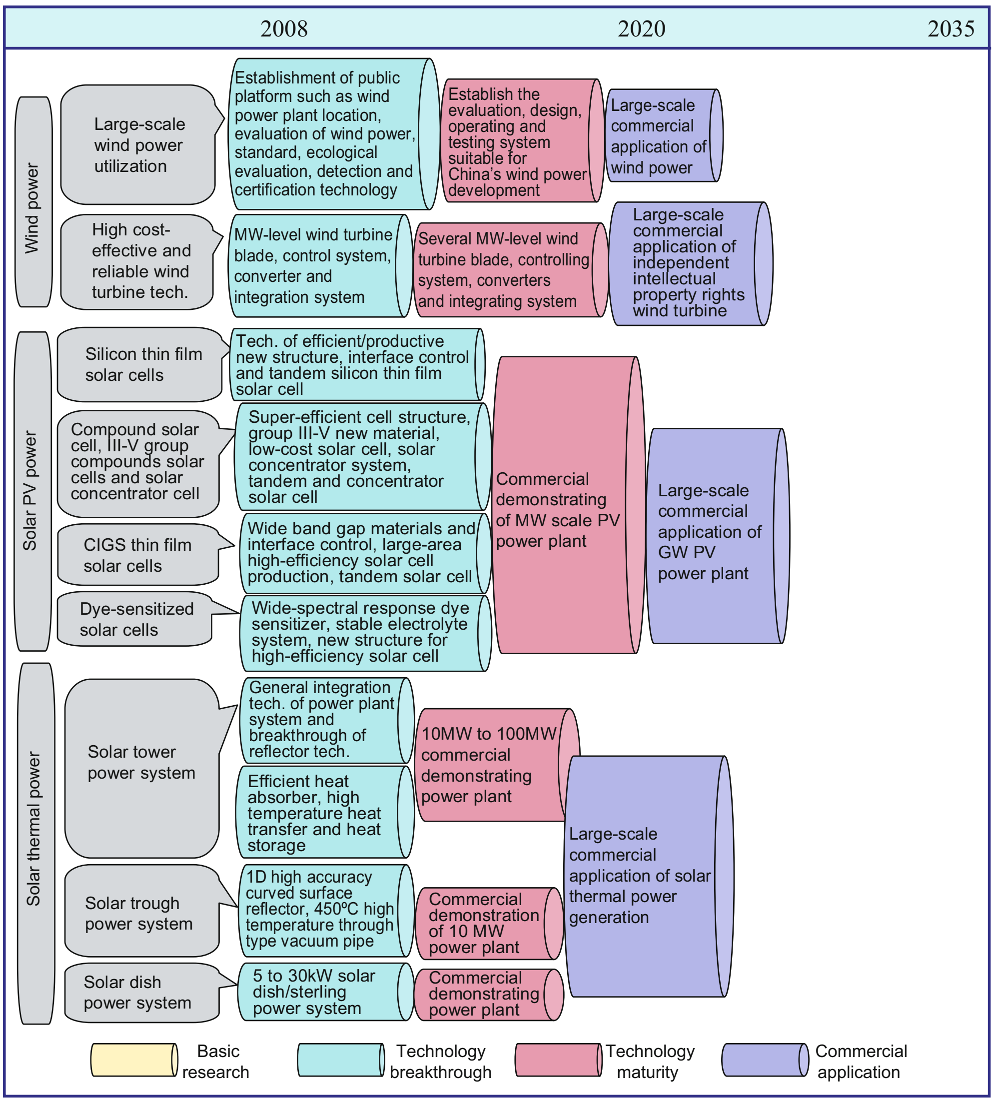


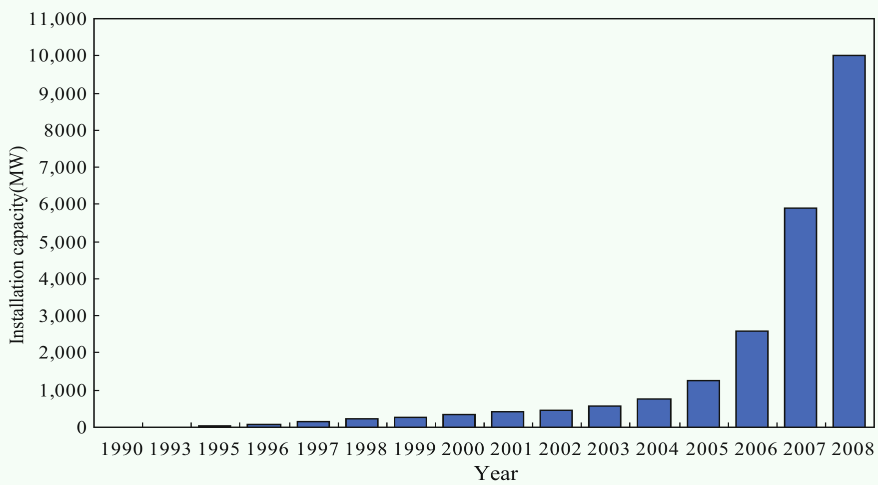
Fig. 4.5 Roadmap of the large-scale power generation technology from renewable energy resources

Wind Power in China—Present and Future

Recently, wind power develops rapidly around the world, improving significantly both in scale and standard. The unit capacity has improved from tens of kilowatt to hundreds, and hence to megawatt which as prevailing at the moment. Generators, from fixed pitch wind turbine to variable-speed constant-frequency doubly fed induction wind turbine, and hence to directly driven wind turbine. As the unit capacity and control technology of wind power generation are both improved, the type of wind power generation system changed from distributive to concentrated large-scale wind power plant. At present, there are already a number of large-scale wind power plants existing in China, the largest of which found in Inner Mongolia. This wind power plant has an installation capacity of 120.7 MW. There are four wind power plants having a installation capacity above 100 MW.

In the past two years, the process of wind power construction has been thriving, demonstrating an increasing development trend(as shown in the chart). In 2007, there is an addition of installation capacity of 3.3 GW. There were wind power enterprises springing up all around the country, including Sinovel Wind Co., Ltd., Tianjin Dongqi Wind Turbine Blade Engineering Co., Ltd. , HEAG, Zhejiang Windey Wind Generating Engineering Co., Ltd., HCAF, Xinyu Jiangsu, Mingyang Electric, Shanghai Electric, Hpec, Beijing Beizhong Steam Turbine Generator Co., Ltd., Zhuzhou CSR Times Electric Co., Ltd., United Power, CSIC(Chongqing) Haizhuang Windpower Equipment Co., Ltd., Hara XEMC Windpower Co., Ltd., YH Group. Wind power plants spread around the nation, such as Ximeng Wind Power Station, Wuzhongqi, Changzhou, Changdao (Shandong), Dafeng (Jiangsu), Jimo (Qingdao), Guanting Reservoir, Xiangshui (Jiangsu), are developing at a thriving rate.

It is estimated that in the near future, the growth rate of installation capacity will be maintained at 5 GW. In 2010, the accumulated installation capacity will amount to 14—15 GW, and 80—100 GW in 2020. It is possible that the accumulated installation capacity will exceed 120 GW in 2020, which is 10% of the total installation capacity of power generation, and wind power will become the third after fire and water power as the largest power generating force.



Installation Capacity in China from 1990 to 2008

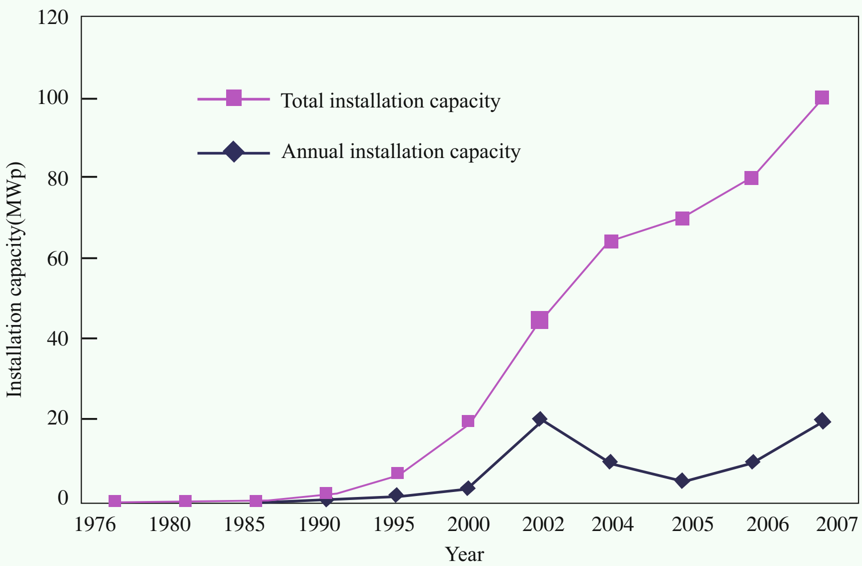
Source: Jianlin Li, etc. 2008. The power electronics converter technology. Beijing: Machinery Industry Press

Solar PV Power Generation in China

In 2007, the total installation amount of PV system in China is approximately 20 MWp, 1.84% of the production of solar cells, 1088 MWp, that year. This indicated that 98% of the production had been exported. By the end of 2007, the accumulated installation capacity of PV system in China amounted to 100 MWp (approximately equal to nearly 1% of the world's.

52% of PV implementation are commercial (communication, industrial application and solar PV product), 48% supported by the government, in which 5% is parallel power (BIPV and onshore PV power plant) and 95% is independent PV system.

In 2007, independent PV application reaches 18 MWp, account for 90% of the additional market share; for parallel PV system, that is 2 MWp and 10%. Independent system still dominates in the Chinese market, the parallel PV power having a very small portion. In comparison, Europe has a ratio of parallel PV system at 99% in 2006 to 2007. By the end of 2007, the accumulated installation of PV system globally reached 12 GW, in which 10 GW was parallel PV power, i.e. 83% of the market. This indicates that China's PV implementation is still at its initial stage, and the understanding on the strategic importance of parallel PV power should be improved. The key term of *renewable energy law*, "online electric fee", should be implemented as soon as possible, and the development of parallel PV power should hence be accelerated.



The trend of annual and accumulated installation capacity of China's PV system from 1976 to 2007

The installation amount and market share of China's PV system in 2007

Application field	Installation amount (MWp)	Market share(%)
PV product(street lamp, lawn lamp, sightseeing lighting, LED, traffic signal, etc.)	6	30

(Continued)

Application field		Installation amount (MWp)	Market share(%)
Communication and industrial usage		3	15
Electricitization in rural areas (including rural road lamp)		9	45
Parallel PV power generation	Non light condensation	1.7	8.5
	Low power condensation(Inner Mongolia, Shanghai)	0.3	1.5
Total		20	100

As for PV parallel power generation, the Ministry of Science and Technology has arranged five MWp-level parallel demonstrations in the "863 Program" project of the 11th five-year-plan. The implementation of such a project will actively promote the development of PV parallel power generation. Recently, many local governments have begun with the construction of PV parallel power plant. Being the largest PV power generation project in China, the 10 MW parallel PV power generation project in Dunhuang, Gansu Province, is in its final stage next to completion. Huge investment plans of both local and central governments will follow closely. Thereupon, the government subsidies and the redefinition of power fee will, in the industry, be the mostly concerned key problems in the large-scale initiation of Chinese PV power generation market.

Source: The Advance Energy Technology Innovation Base of Bureau of Hi-Tech Research and Development Chinese Academy of Sciences, 2008. Solar PV power generation. Energy Strategy and Technology Reference, 1.

Current Development of Solar Thermal Power Generation

(1) Current Development of Foreign Countries

Since the crude oil crisis in the 1970s, the major developed countries in the world such as the USA, Spain, Germany, Switzerland, France, Italy and Japan have all initiated large-scale R&D projects in solar thermal power generation. In 1981, 9 countries in Europe, including France, Italy and Germany, jointly established the world's first solar tower power plant, which operated at a rated power of 1 MWe in parallel. Thereupon, the USA, Spain, Germany, Switzerland, France, Italy, Israel, Russia and Japan built solar thermal power plants one by one. Moreover, some developing countries such as India, Egypt, Mexico, Algeria and Morocco, with the support of the Global Environment Facility, began with developing solar thermal power technology in this century.

In the 20th century the technology of solar thermal power was at a stage of trial and demonstration, and 25 years of R&D results and experiences accumulated. Since the beginning of this century, both the living condition of human and the restraints of the economic condition increasingly demand the prevailing use of a clean and low price power source. This fueled the rapid development of solar thermal power, with the foundation built in the last century, all around the world. This new power source, capable to generate power in a large-scale with a very low price, is developing rapidly. At present, the technology of solar thermal power is mature and reliable; the cost of key facilities in power plants is also significantly lowered. In the year of 2007, the total installation capacity of solar thermal power generation reached 100,000 kW globally.

Currently there are 13 tower stations, 14 trough stations and 7 dish stations constructed around the world, among which some tower systems and trough systems are commercially operated. The company Luz of the U.S. built 9 power plants in the desert of California in the 1980s, having a total capacity of 354 MW and producing 1.08 billion kW·h annually. They are still operated commercially and incorporated into the power grid of South California Edison Power Company. PS 10 in Spain, was established and started commercial operation in July, 2007, as shown in Fig.1. Since the 1990s, businesses and R&D institutions in developed countries such as the USA, Germany have been supported financially by their governments, and their research on dish system has been accelerated by establishing projects and plans. This gives an impetus to the commercialization of this kind of solar thermal power generation.

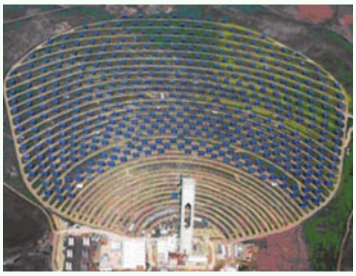


Fig. 1 Panorama of PS10, Spain

(2) The Development of Solar Thermal Power in China

China's research on the utilization of solar thermal power did not begin late, but was lagging behind owing to several reasons. At the end of the 20th century, thanks to the great effort of experts in advocating and propagating, the related departments in the government started paying attention and hence substantially supporting the R&D in this field.

Solar dish systems. During the 10th five-year-plan, the Institute of Electrical Engineering, Chinese Academy of Sciences, cooperated with Hi-min Solar and China Xinjiang Sunoasis Co., Ltd., developed four single and multi-dish concentrators, among which the multi-dish type was capable to endure a temperature of 1600 ℃ at its focus. Used in the Solar Stirling power generation system, they started generating power since 2007 (Fig.2). According to renowned experts in Spain, the U.S., Germany, Korea, Australia, these devices meet the international advanced standard both in terms of technology and economic concerns.

Fig. 2 Multi-dish concentrator developed by Institute of Electrical Engineering, Chinese Academy of Sciences

Fig. 3 Trough concentrator developed by the Institute of Electrical Engineering, Chinese Academy of Sciences

Trough concentrator. Institute of Electrical Engineering and Institute of Engineering Thermophysics of Chinese Academy of Sciences, together with Hi-min Solar, successfully developed a set of trough concentrator which have a total length of 12m and a width of 2.5m of aperture(Fig.3). Through the research on unidirectional parabolic reflector, the problem of curved-mirrors production using flat glass is solved. The super-light structured reflector is also developed applying compound honeycomb technology. It is suitable to be implemented in deserts as it adapts the hydraulic transmission mode.

Tower power system. As for solar tower power generation, scientists in China have engaged into a series of research from key technology to system integration. Hehai University has cooperated with Israel and built a 70 kWe tower plant using a combination of solar and fuel power in Jiangning, Jiangsu Province(Fig. 4). There are totally 30 heliostats, each of them having an area of 40 m^2 for reflection. In the 11^{th} five-year-plan, the Ministry of Science and Technology had set up the key project in 863 Program: the technology and system demonstration of Solar Thermal Power Generation. This project is undertaken by Institute of Electrical Engineering of Chinese Academy of Sciences. As part of the project, the first MW-level solar tower power plant in China will be built in Yanqing County, Beijing(Fig. 5). Planned to begin operation in 2010, the fulfillment of this project will signify China's entry to a new stage of solar thermal power generation technology.

Fig. 4 Demonstrating power plant in Nanjing, built by Hehai University

Fig. 5 Panorama of 1MW solar tower plant in Yanqing county, Beijing

Source: Zhang M. 2008. Solar thermal power technologies. High-Technology & Industrialization, 7: 10

4.6 Enhanced Geothermal Systems Technology for Deep Geothermal Resources

4.6.1 Overview

The concept of EGS (Enhanced Geothermal Systems) technology was put forward on the basis of Hot Dry Rock mining technology. Many developed countries in Europe and America have gone through the research and development process for 30 years. Water or other working fluid (e.g. CO_2) injected from the injection well, circulates underground through artificially created connecting fractures. Water is heated through contacting with the rock formation and then returns to the ground via a producing well, forming a closed circuit. EGS is an artificial geothermal system with geothermal reservoirs constructed through engineering measures that allows people to exploit considerable amount of deep geothermal energy from low permeability rock masses economically.

America, Australia and some other countries have fully confirmed the contribution of deep geothermal resource and EGS for the future of mankind. They take EGS as a practical technology. In addition, the resource is widely distributed, and the high temperature oil field zone has huge potential in exploiting deep geothermal energy. At present, the geothermal anomalous areas which are buried relatively shallow are with the best exploiting conditions. As the technology develops, the exploiting cost will continue to go down, which can be as low as one fourth of the current cost. American government has increased their investment on the research and development of EGS. Australian government, with the preferential policy, has founded some national geothermal resource organizations and joint-stock geothermal companies. It has also conducted some field tests of using EGS technology to exploit deep geothermal resource in some key areas in the country.

The geothermal resource condition in China is similar to America's and is better than Australia's. Preliminarily judged from the geothermal and geological conditions of China, the crusts of high temperature anomalous areas in southwest and southeast China possess a better exploiting condition. The basins in north and northeast China with relatively high crust temperature are also good for being exploited. In terms of technical capacity, China hasn't carried out large scale specialized EGS technology research and development programs, but has done some research on improving the exploiting efficiency in low-permeability geothermal energy reservoirs. Furthermore, solid experience and technology have been accumulated after years of research, development and practice. Thus, China is taking the lead in aspect of oil recovery. Undoubtedly, the technologies can make great contributions to deep geothermal energy exploiting project. And with further improvement a specialized technology of exploiting and utilizing deep geothermal resource can be developed.

4.6.2 Key Science and Technology Issues

The key technologies of EGS are: deep geothermal resource definition and reserve assessment technology; EGS site selection, investigation and description technology; potential technology to reduce cost and improve efficiency of EGS (e.g. numerical simulation technology). Some other specific technologies are also important, such as deep well pump, fracture characterization, high-temperature logging, fluid imaging, excitation prediction model, tracer and tracer test data interpretation, and inter-layer sealing technology.

4.6.3 Science and Technology Objectives at Different Time Nodes

EGS hasn't been listed in the agenda, in view of the big energy base and the late start of deep geothermal energy technology development. 2020 was set to be a year of technology maturity, and 2035 as a year to realize large scale exploiting. The target of geothermal electric power generation is to reach 5% to 10% of the total national installed capacities. It can replace about 300 million tons of standard coal and reduce 800 million tons of CO_2 emission. Compared with America, Australia and some other countries, this estimation is prudent.

4.6.4 Science and Technology Development Roadmap

Science and technology development roadmap for the enhanced geothermal systems technology for deep geothermal resources is shown in Fig.4.6.

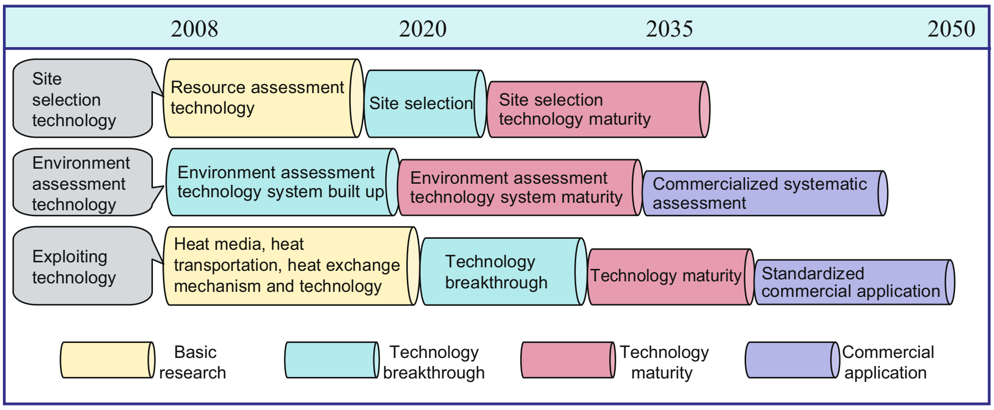


Fig. 4.6 Roadmap of enhanced geothermal systems technology for deep geothermal resources

4.7 Hydrogen Utilization Technology

4.7.1 Overview

As an ideal energy carrier which can be acquired with various approaches, hydrogen is an important bridge to convert fossil energy to renewable energy. Its fuel cell power and distributed functional system are clean and flexible. Thereby it offers a new important form for final energy use. Hydrogen energy is a new global research hotspot. The significance of hydrogen energy as a future energy in China is embodied in the following: to replace oil as a transportation fuel; to improve the energy use efficiency as an efficient energy carrier; to reduce emission as a low pollution fuel; to develop distributed energy to improve the security and efficiency of energy system; and to reduce CO_2 emission.

4.7.2 Key Science and Technology Issues

(1) Efficient, Clean and Low Cost Hydrogen Production Technology

The current technology to produce hydrogen with large-scale fossil fuel has been quite mature, but not efficient enough with 50% to 60% production rate. Calculated with the life cycle method of "from mine to wheel", the hydrogen production rate needs to reach 70%, in order to make the overall use efficiency of fuel cell vehicles reach 40% or beyond (15% to 30% of petrol vehicle). Thus, it is needed to focus on improving the hydrogen production efficiency, lowering cost, optimizing system integration technology, and reducing CO_2. In addition, it is needed to develop the research of distributed field hydrogen production technology, take advantage of the current energy transportation infrastructure (e.g. electric power, natural gas pipeline network, vehicles) to transport raw material for hydrogen production and energy to the final use spot, and to produce hydrogen on the spot. This technology process has been regarded as the best way to establish hydrogen refueling station and to offer distributed hydrogen resource for fuel cells at present because field hydrogen production can avoid high cost transportation process and doesn't need rebuilt huge transportation infrastructures. Moreover, supporting all kinds of "renewable energy hydrogen production technology" including solar power, nuclear power and biomass should be emphasized. It's also essential to increase the proportion of hydrogen produced with renewable energy and nuclear power.

(2) High Capacity Hydrogen Storage Technology

Hydrogen storage is an important means to utilize hydrogen energy and it is required to be of high security and efficiency, small volume, light weight, low cost and high density. There is still a long way to go to put the current storage means into practice, and it has become a bottleneck for large-scale hydrogen energy application. Thus, further research is needed on hydrogen storage mechanisms and original innovations of theories, in the hope of discovering new hydrogen storage mechanisms to boost the innovation of the technology and material and to explore new storage-release mechanisms and technologies as well.

(3) Fuel Cell Technology

Fuel cell technology is the energy consumption terminal of hydrogen energy application. Though fuel cell has many commercial demonstrations in aspects of mobile power source, dispersed power station and micro power supply, some key technology problems haven't been appropriately resolved and commercial promotion proceeds slowly. The main problems are: ① the cost of the key material and components (electrolyte membrane, bipolar plate and catalyst) for fuel cell is too high; ② the circulation system of fuel and oxidant, the management system and management control system of water and heat need further optimization; ③ the long-running cell performance especially stability, reliability and environment adaptability need further improvement; ④ the cell construction and preparation technology need further optimization.

4.7.3 Science and Technology Objectives at Different Time Nodes

China will gradually develop hydrogen energy industry in the fields of transportation (mobile source) and distributed power generation (stationary source). According to the forecast of related authoritative experts, 50 years later, the hydrogen energy industry of China will be like as follows.

From 2008 to 2020: the fuel cell vehicles are still in the research and development demonstration stage and small-scale commercialized stage. In 2020, the output of cell vehicles will take up 1% of the whole, namely 150,000 vehicles; the distributed generating capacity of fuel cells will reach 100,000 kW, which takes up 0.014% of the whole generating capacity; the heat load of fuel cell vehicles will amount to 200,000 kW which is 0.15% of the whole.

From 2020 to 2035: the fuel cell vehicles will be in the commercial promotion and application stage. In 2030, the output will account for 5% to 8% of the whole which is millions of cell vehicles; the quantity of possessed fuel cell vehicles will reach 10 million; the distributed generating capacity of fuel cell will arrive at 1 million kW, which takes up 0.1% of the whole; the heat load of fuel cell vehicles will be 2 GW, which takes up 1.5% of the whole.

From 2035 to 2050: the fuel cell vehicles will be in the commercial promotion and application stage. In 2050, the fuel cell output will take up 1/3 of the whole, which means ten million fuel cell vehicles will be produced; the quantity of possessed fuel cell vehicles will exceed 50 million; the distributed generating capacity of fuel cell will be 5 GW, which takes up 0.25% of the whole; the heat load of fuel cell vehicles will reach 10 GW, which takes up 7.5% of the whole.

4.7.4 Science and Technology Development Roadmap

Science and technology development roadmap for hydrogen utilization technology is shown in Fig.4.7.

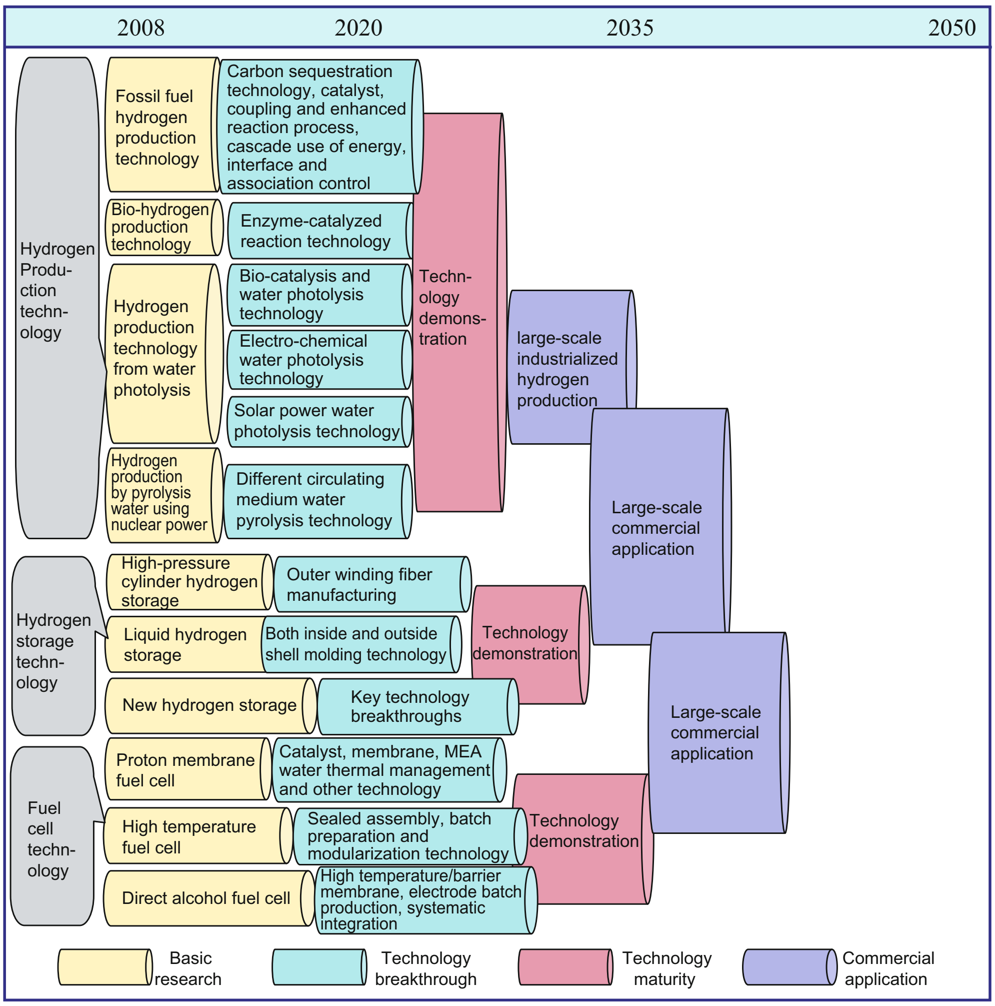


Fig. 4.7 Hydrogen utilization technology roadmap

Hydrogen Energy System for the Future

The idea of taking hydrogen as a kind of energy carrier initially appeared in the fiction *The Mysterious Island* by Jules Verne in 1874. In the book, he wrote: "I believe that one day water can be used as fuel, and the hydrogen and oxygen which compose the water can be used separately or together. This practice will furnish endless resource for heat and light which coal can't compete with. So I believe once coal is used up, water can be used for heating. Water will be the future coal."

Hydrogen is a clean energy carrier for chemical energy, because it only generates water after reaction or burn with oxygen in the atmosphere. It's also a kind of secondary energy because it has no direct resource reservoir. Just like electricity, it needs to be acquired from other primary energy.

As a clean energy carrier, hydrogen has various characteristics: it can match and be compatible with every existing energy system; it can be easily converted into electricity and heat; it can be produced from many resources; it is highly convertible; it can dispose CO_2 in batches, etc. Therefore, hydrogen energy (to use hydrogen as an energy carrier) is considered to be a vital bridge to convert fossil energy to renewable energy and to realize sustainable energy supply and circulation.

In hydrogen energy system, hydrogen production is the fundamental of application. Hydrogen storage and transportation is the key process for large-scale hydrogen energy application, and fuel cell is the core technology(Fig.1). As commodities, hydrogen and electric energy stand equal and compliment with each other as final energy. Fig. 2 demonstrates the future "ideal" energy system circulation and supply with water and hydrogen as its energy carrier.

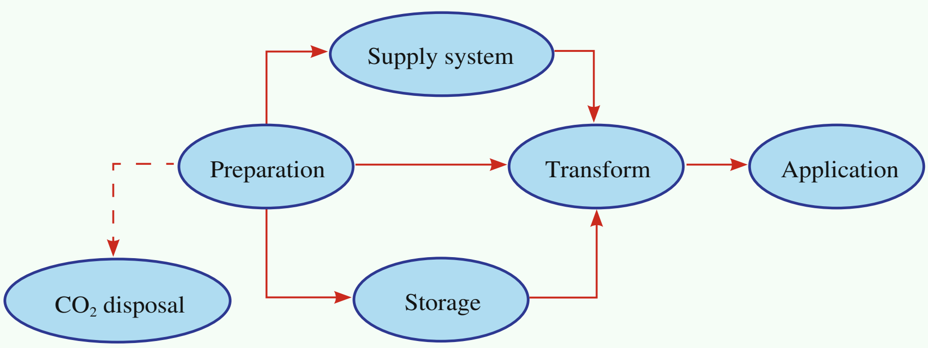


Fig. 1 Structure of future hydrogen energy system

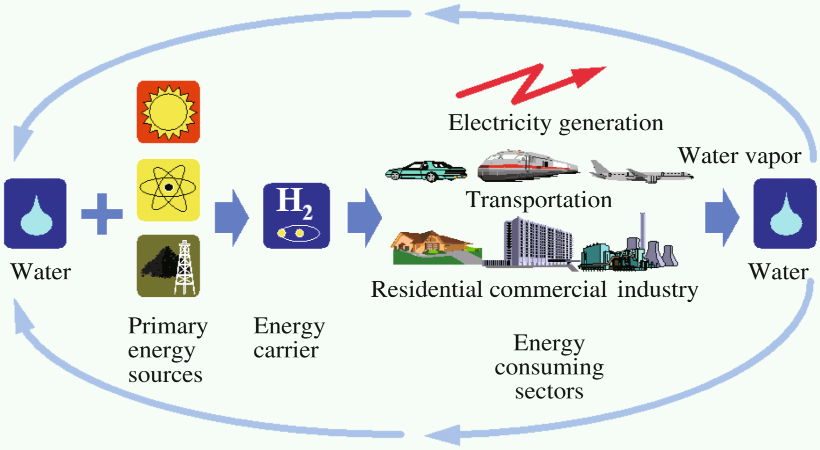


Fig. 2 Cyclic graph for future "ideal" energy system with hydrogen as energy carrier

Source: Jiang Zemin. 2008. Reflections on energy issues in China. Journal of Shanghai Jiaotong university, 42(3):354–355

4.8 Natural Gas Hydrate (NGH) Development and Utilization Technology

4.8.1 Overview

The research about NGH began in the 1990s in China, and at present it has been in a research stage of the survey, the explorations, evaluations and the indoor simulations of hydrate resources. Chinese Academy of Sciences and Guangzhou Marine Geological Survey have delineated 4 prospect areas of NGH resources in Shenhu sea waters of South China Sea. In May 2007, Guangzhou Marine Geological Survey obtained NGH physical samples for the first time from Shenhu sea waters of South China Sea, which had proven that there are a large number of NGH in China's sea areas. China is the fourth country that has obtained NGH physical samples following America, Japan, India, which has provided China's excellent opportunities to do NGH researches. It is fact that there is a wide gap between China's research capacity and the advanced level, but so far, no NGH exploitation technology in the world has been internationally recognized as an economical, safe and efficient one. All the related technologies are still in the stages of research and experiment. Thus, it is possible for China to reduce the research capacity gap. At the same time, ore-forming environment with abundance of NGH in permafrost regions of Qinghai-Tibet and South China Sea has provided China with broad prospect for application.The development and utilization of NGH resources involve in those in the permafrost regions and the ocean areas.

4.8.2 Key Science and Technology Issues

Main scientific and technical issues include the survey and the assessment, the exploitation technology, the safety and the impact on environment of NGH resources.

(1) Survey and Assessment of NGH Resources

Make the exploration evaluation on the distribution, the total amount, the formation characteristics and the exploitable amount of NGH resources in the sea areas, and make prospect on NGH in permafrost regions.

(2) Exploitation Technology

Economical, safe and efficient NGH exploitation technology is a crucial factor for NGH resources development.

(3) Safety and Impact on Environment

NGH has an important impact on global climate change. Hence, the researches on NGH global Carbon Cycle and Controlled Release Technology of Methane Hydrate is the prerequisite to achieve NGH resources development. The undersea landslide, the collapse, the earthquake and the tsunami caused by NGH decomposition, especially in the exploitation of marine NGH, are major issues need to be solved in NGH development.

4.8.3 Science and Technology Objectives at Different Time Nodes

From 2008 to 2020: establish the fundamental theories and the technology systems which are mainly about NGH development in Chinese sea areas, including the reservoir formation, the survey and assessment, the exploitation, the utilization, and impact on environment; complete the survey, exploration, and assessment of NGH resources in Chinese sea areas; develop Natural Gas Hydrate exploration and identification technologies; quantitatively evaluate NGH's role in Global Carbon Cycle and global climate change; select the NGH exploiting regions to do the exploiting feasibility research; develop a safe, environmentally friendly, efficient and economical exploiting technology of NGH; carry out the exploiting test of NGH in the sea; develop the engineering technology, disaster early warning technology and disaster prevention and treatment technology for NGH's safe production; establish the theoretical system for the reservoir formation and exploration of NGH recourses and the technological development system of NGH recourses in permafrost regions.

From 2021 to 2035: complete the commercial test exploitation of NGH in the sea, and achieve the level of commercial production; develop the engineering technology, disaster early warning technology, prevention and treatment technology for NGH's safe production; once NGH is found in permafrost regions, the related further research will be done as soon as possible.

From 2036 to 2050: the commercial exploitation of NGH in the sea.

4.8.4 Science and Technology Development Roadmap

Science and technology development roadmap for natural gas hydrate's (NGH) development and utilization technology is shown in Fig.4.8.

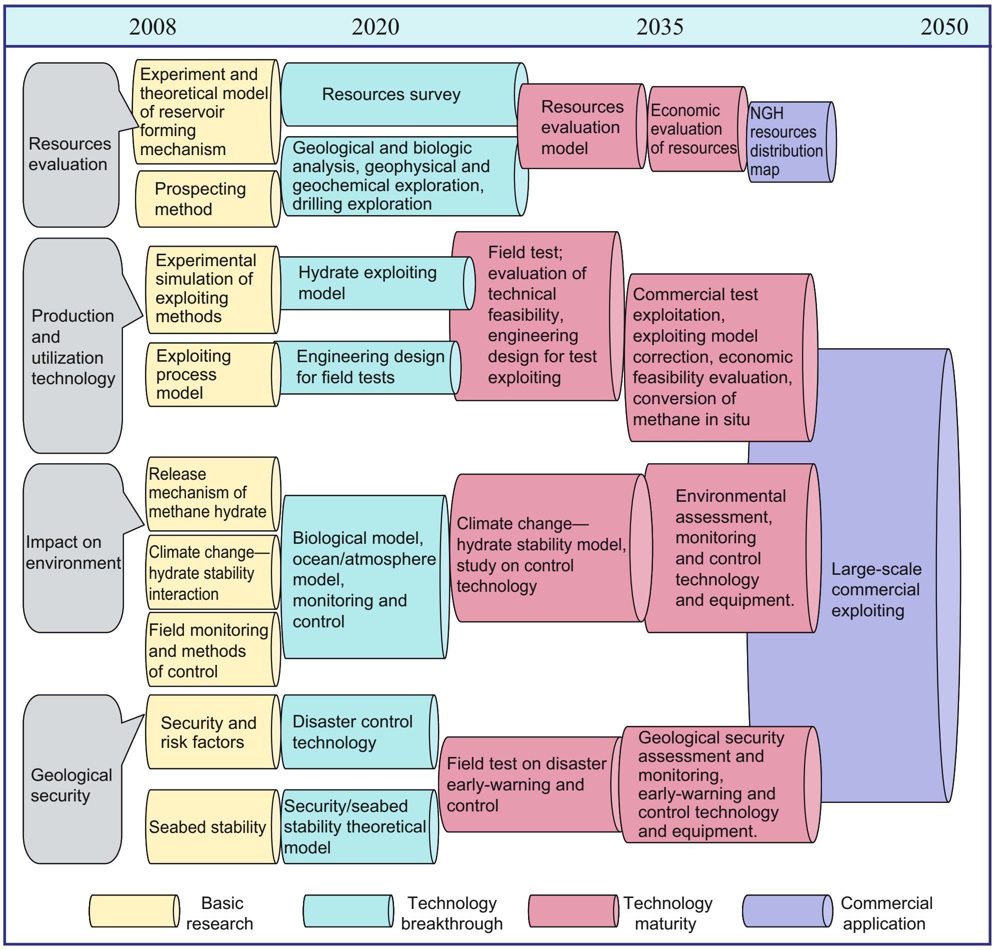
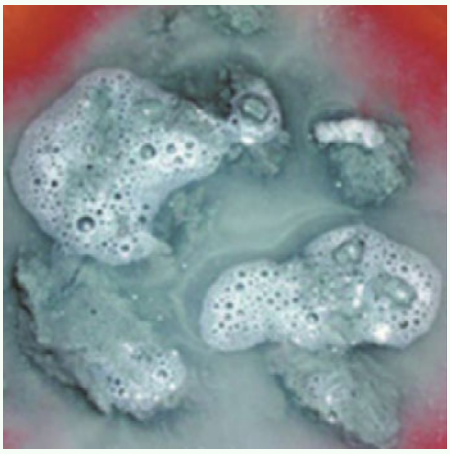


Fig. 4.8 Natural gas hydrate's (NGH) development and utilization technology roadmap

China's First Natural Gas Hydrate (NGH) Physical Samples

It took 9 years, with total accumulative investment of 500 million Chinese yuan, for China to obtain successfully NGH physical samples, "flammable ice", in the northern of South China Sea. Thus, China has become the fourth country that has obtained NGH physical samples following American, Japan, India, through the state research and development plan.



China's first NGH physical samples

Zhang Hongtao, the deputy director of China Geological Survey, in a press conference held by Ministry of Land and Resources on 5th, 2007, announced that in the wee hours of 1st May, 2007,Guangzhou Marine Geological Survey successfully obtained NGH physical samples for the first time from Shenhu sea waters of South China Sea, which had proven that there are a large number of NGH in China's sea areas, and marked that the research level of NGH in China ranked among the world's most advanced.

According to preliminary prediction, the prospective resources of NGH in northern slope of the South China Sea are up to 10 billion tons of oil equivalent. Shenhu sea areas of the South China Sea have become the 24th region in the world where NGH physical samples are obtained.

This time of the drilling voyage was organized by China Geological Survey, implemented by Guangzhou Marine Geological Survey, and the sample was obtained successfully at the first attempt. It was learned that NGH samples were obtained in the first and forth site. Samples obtained in the first site were found in water depth of 1245 m and in depth of 183 to 201 m below the seabed. Hydrate abundance was 20%, thickness of deposits with hydrate was 18m, methane content in the gas was 99.7%. The samples obtained in the forth station were found at 191 to 225 m below the seabed, and 1245 m water depth. Hydrate abundance was 20% to 43%, the thickness of deposits with hydrate was 34m, methane content in the gas was 99.8%.

After obtaining the core of seabed multi-segment sediments, the core was immediately analyzed with 18 test methods, such as X-ray image analysis, infrared scanning, in situ. Finally it was confirmed that many segments contained evenly distributed NGH and NGH in the form of disseminated impregnation. When the core was quickly cut opened, most of the samples decomposed and gasified immediately because of pressure decrease and temperature increase. However, on the fresh-cut layer we could see clearly the tiny dotlike white crystal of NGH. When the pressure core was immersed into water, a large number of gas bubbles poured out. When the released gas was directly ignited, its flame was very strong.

Source: http://news.xinhuanet.com/tech/2007-06/05/content_6201257.htm

4.9 The New Nuclear Power and Nuclear Waste Treatment Technology

4.9.1 Overview

Nuclear power technology has gone through three generations of development. The fourth-generation nuclear power technology is in the process of R&D.

The development and construction of nuclear power plants started in the 1950s. In 1954, the former Soviet Union built an experimental nuclear power plant whose electric power was 5 MW. In 1957, the United States built Shipping port prototype nuclear power plant whose electric power was 90 MW. The experimental and prototype nuclear power plants mentioned above are known as the first generation of nuclear power plant.

In the late 1960s and 1970s, on the basis of experimental and prototype nuclear power plant, they further built some new kinds of nuclear power plants including PWR, BWR, CANDU, etc., whose electric power was over 300 MW. At present, more than 400 nuclear power plants are in commercial operation in the world. They are mostly built in that period. They are known as the second generation of nuclear power plant.

In the 1990s, to abate the negative impact of serious accidents that happened at Three Mile Island and Chernobyl nuclear power plant, the world nuclear power industry concentrated its resources to conduct related research and tackle difficult problems. The United States and Europe had separately introduced *Utility Requirements Document* and *European Utility Requirements*. The nuclear power plants which meet one of these two documents are known as the third generation nuclear power plant around the world. At present, the relatively mature third-generation nuclear power PWR has three models which are AP-1000, EPR and System80 +.

The fourth generation nuclear energy system is an advanced one which can effectively prevent the nuclear proliferation. It has better security, strong economic competitiveness and less nuclear waste. It represents both the development trend and the technology frontier of advanced nuclear energy system. In 2001, the United States took the lead in setting up the Generation IV International Forum with the United Kingdom, Switzerland, South Korea, South Africa, Japan, France, Canada, Brazil, Argentina as well as the European Atomic Energy Community. The forum ended with the signing of "Charter" whose purpose is to research and develop the fourth generation nuclear energy system, which is expected to be put into operation before 2030. The 10 countries above-mentioned officially become the members of GIF. In addition, the International Atomic Energy Agency and the OECD Nuclear Energy Agency are observers of GIF, and China became the member in 2006.

China begins to develop rapidly in its nuclear power technology. However, compared with the international advanced level, China still falls behind by a large gap. As a result, our current development guideline is market-for-technology that we introduce the technology, digest and assimilate it and then make re-innovation. But to attain China's own intellectual property rights of technology in the future nuclear power development and to form the national nuclear industry with Chinese characteristics, China should strengthen its development of new nuclear technologies and nuclear waste treatment technologies (including separation technology, fast neutron transmutation technologies like accelerator driven subcritical system, and final disposal technologies, etc.) by the year 2050, which will help us to raise the level of science and technology in terms of nuclear power generation and address the issues of nuclear waste treatment and reclamation in the process of nuclear power operation.

4.9.2 Key Science and Technology Issues

1) The sustainable development of nuclear power involves three levels of key technologies. The first one is to improve and enhance the level of thermal reactors nuclear energy system from the "second generation" to the "third generation". The second one is to develop the fast reactors nuclear energy system and the closed fuel cycle technology so that the optimization for uranium resources utilization can be achieved. The third one is to develop the transmutation technology of minor actinide nuclides and long-lived fission products which will make the minimization of nuclear waste come true.

The three levels of advanced nuclear energy technology and the nuclear fuel cycle technology should be developed in a coordinated way and support each other. We must take them as a whole system and make unified overall plans.

2) The fourth generation nuclear power technology. The objective of the fourth generation nuclear energy system development is to innovatively develop a new generation of nuclear energy system by 2030 or so. It will have remarkable advancement and competitiveness in terms of its security, economy, sustainable development, nonproliferation, anti-terrorist attack, etc. It not only considers the nuclear reactor device used for power generation or hydrogen production, but also includes the nuclear fuel cycle to form a complete system of nuclear energy utilization. The fourth generation nuclear energy system takes six kinds of reactors as priority target for research and development: ① VHTR: the helium cooled high temperature (1,000 to 1,200 °C) reactor which is mainly used for hydrogen production or used for hydrogen production and power generation; ② GFR: the helium for thermal agent of fast neutron reactor; ③ SFR: sodium for thermal agent of fast neutron reactor; ④ LFR: lead alloy cooled fast neutron reactor agent; ⑤ SCWR: supercritical water reactor; ⑥ MSR: molten salt reactor. There are two high temperature gas cooled reactors, two types of liquid metal (sodium, lead alloy) reactors, a supercritical water reactor and a molten salt reactor in the nuclear energy system. We will select one or several reactors around 2020 and build innovative prototype group

system demonstration around 2025. Then starting from approximately 2030 (according to the 2009 European research strategy schedule for sustainable development of nuclear energy, it may changed to 2040), we can widely use the fourth generation nuclear power plant system.

3) Accelerator driven system (ADS). The spent fuel of nuclear power plant contains minor actinide nuclides (MAs) and long-lived fission products which will take several million years to achieve a comparable level of radioactive toxicity compared with natural uranium mine. These nuclides will have fissile reaction in the fast-neutron spectra. So, the fast reactor can be used to transmute these nuclides to be general fission products. However, when we transmute MAs in fast reactor, the reactor safety will be lowered. In addition, it is even more important to know that the breeding doubling time can be increased and the breeding capacity will be sacrificed if the fast reactor is used to have transmutation role during it's breeding operation. Therefore, from the point of view of China's energy demand and resources pressure brought by large-scale development of nuclear power, the fast reactor should focus on the breeding of nuclear fuel. ADS should focus on nuclear waste transmutation. At present, the ADS is one of the powerful tools to transmute nuclear waste. The International Atomic Energy Agency has listed it into new nuclear energy systems and it is known as the "new nuclear energy system of nuclear waste transmutation and energy generation." The research results will have significant resource efficiency, security benefit and environmental benefit. This is a new technology approach worthy of exploration for the sustainable development of China's nuclear fission energy. The research and development process of ADS system will play an important role in greatly driving technology development in related fields. At the same time, it also provides a possibility of producing the nuclear materials and opens up a promising future for the thorium resources utilization.

Mid-long Term Development Plan of China's Nuclear Power

In October, 2007, the National Development and Reform Commission (NDRC) adopted the *Medium- and Long-term Nuclear Power Development Plan*. In accordance with the needs of protecting security of energy supplies and optimizing the power structure, after making overall consideration towards China's technological strength, construction cycle, equipment manufacturing and self provision as well as nuclear fuel supply, etc., we can strive to achieve a targeted 40 GW installed capacity of running nuclear power by 2020. The annual nuclear power generation capacity will reach 260 to 280 GW·h. Based on the present 16.968 GW nuclear power capacity that is under construction and in operation, the new production of nuclear power installed capacity will reach approximately 23 GW. At the same time, considering the follow-up development of nuclear power, China should keep the installed capacity of ongoing nuclear power projects around 18 GW by the end of 2020.

In the aspect of nuclear power self-reliance, the advanced 1 MW grade PWR nuclear power will achieve the level of self-design, self-manufacturing, self-constructing and self-operating. We will fully establish a construction and operation management model which is in line with the international advanced level and form a relatively complete autonomous nuclear power industrial system.

In the aspect of operational performance and nuclear safety, we must make sure that the nuclear power plants which have been put into operation are safe and reliable and the key operational indicators reach the advanced level prescribed by the World Association of Nuclear Operators (WANO). The main design specification of newly started nuclear power plants before the year 2020 must be close to or achieve the same requirements of *United States Nuclear Power User Requirements Documents* (URD) or *European Nuclear Power User Requirements Documents* (EUR).

In the aspect of project construction, the introduction of competition mechanism and the full implementation of the bidding system and contract management system will help improve the project management and further reduce the project cost.

In the aspect of economy, under the precondition of ensuring safety and reliability, we will reduce the operating costs and make the nuclear power on-grid price more competitive, compared with the desulfurized coal-fired power plants in the same region.

In the aspects of nuclear regulations and technical standards, we will establish a complete nuclear power regulation and standard system on nuclear safety, nuclear facilities management, nuclear emergency plan, radioactive waste management as well as engineering design, manufacturing, construction, operation, etc., which are suited to China's conditions and in line with the international practice.

Source: National Development and Reform Commission. 2007. Medium- and Long-Term Nuclear Power Development Plan (2005-2020). http://www.gov.cn/gzdt/att/sitel/20071104/00123f3c4787089759a901.pdf

4.9.3 Science and Technology Objectives at Different Time Nodes

We are aiming at reaching commercial level for China's fast reactor nuclear power system around 2035. we should build the corresponding nuclear fuel cycle system (especially such back-end fuel cycle as the spent fuel reprocessing, uranium-plutonium mixed oxide fuel preparation, metal alloy fuel preparation) and realize the uranium-plutonium closed cycle as soon as possible. We will also rapidly increase the proportion of nuclear power to total power generation. It is expected that the proportion accounted for by China's installed nuclear power capacity in the total installed capacity in 2020, 2035, and 2050 will increase to around 5%, 10%, and 12% respectively. By and large, it can respectively replace 160 million, 440 million and 670 million tons of standard coal consumption and reduce 400 million, 1.2 billion, 1.8 billion emissions of CO_2. Nuclear power, hydropower and clean thermal power constitute the three pillars of sustainable-development energy in our country.

From developing ADS technology now to building full-scale demonstration device, it will experience three stages: small-scale technology integration that means principle verification, the prototype ADS construction and full-scale ADS industrial demonstration. It will take about 30 years to complete this process: ① the main task in the first stage of ten years is to resolve key technical issues of ADS unit; ② the key issue in the second stage of ten years is to complete the medium-scale technology integration; ③ in the third stage of ten years, we will carry out the full-scale technology integration. Then we will build and run a 800MW demonstration thermal power reactor driven by a low beam intensity 10MW beam power accelerator. Then it will be put into experimental operation in the next 15 years (2036 to 2050) to prove its reliability and economy.

4.9.4 Science and Technology development Roadmap

Science and technology development roadmap for new nuclear power and nuclear waste treatment technology is shown in Fig.4.9.

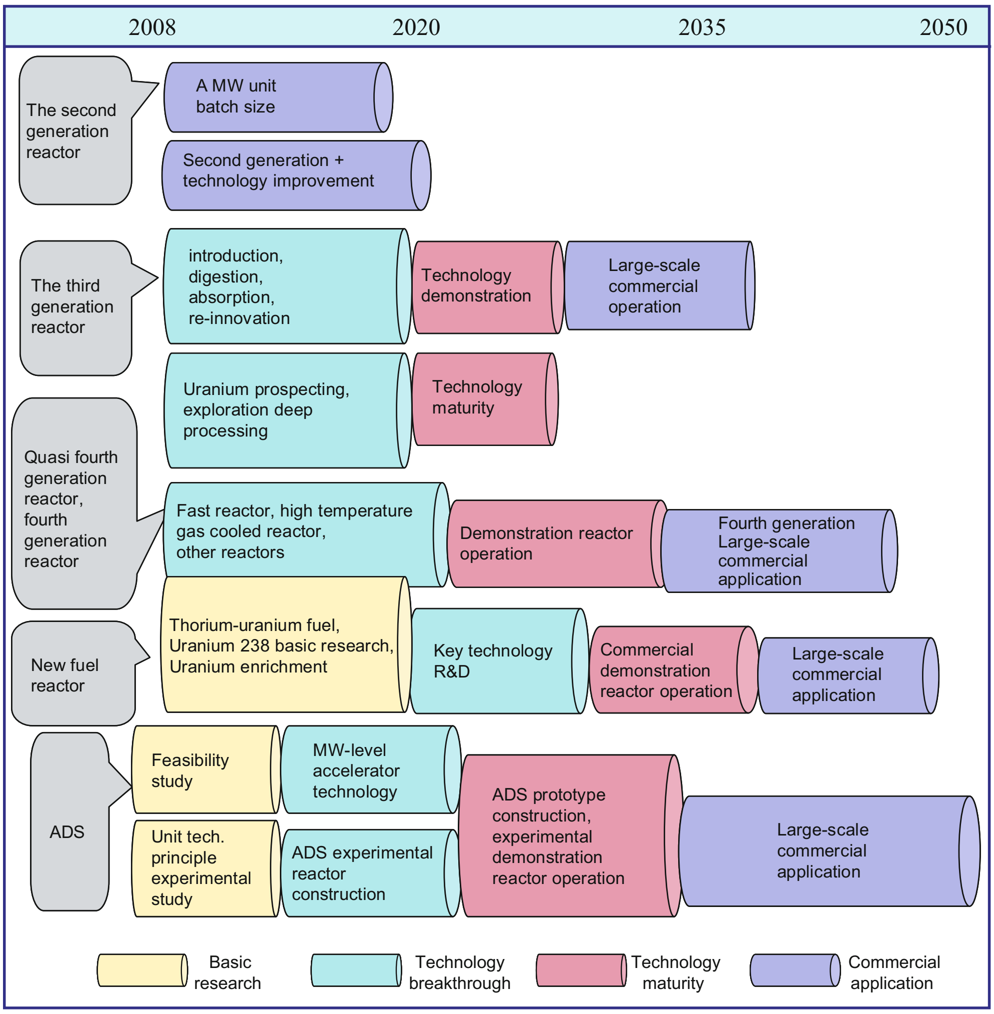


Fig. 4.9 The new nuclear power and nuclear waste treatment technology roadmap

4.10 The Potential Energy Technology

4.10.1 Overview

The new emerging energy techniques include ocean power generation technique, new concept of solar generation technique, nuclear fusion technique, and so on. Though they are not mature today, once key breakthrough is made, those techniques will contribute a lot to meet people's need for special electric power. They will also help reduce the power-generation cost of renewable energy significantly, and provide green power on large scale. Therefore, we can see great potentials from those energy techniques.

(1) Ocean Power Generation

Ocean power is classified as non-carbon energy with large amount of reserves. To make full use of ocean energy is of great significance to both the improvement of energy structure and the reduction of carbon emission. The development of ocean power technique depends on three problems: the cost of generation, anticorrosion capacity of the materials and construction on extreme conditions. Ocean energy is referred to five types of specific energy: wave energy, ocean current energy, tidal energy, thermal energy, and salinity energy.

(2) New-concept Solar Cells

Research on the new-concept solar cells is represented by full spectral InGaN solar cells. Material preparation, combined with structure design and other techniques, forms new-concept solar cell research with IPR. Research in this field is purposed to meet urgent demand from applications of solar energy. As the typical representative of new-concept solar cells, full spectral InGaN solar cells enjoy theoretically photo-electricity conversion efficiency as high as 70% at most. It is also equipped with nitride material which is resistant to radiation. With those advantages, InGaN solar cell is potential to be used in outer space. Other types of new-concept solar cells are also likely to break the limit of photo-electricity conversion efficiency in terms of regular solar cells.

(3) Nuclear Fusion

It is recognized as a new kind of energy utilization in high efficiency. China has made significant progress in nuclear fusion research in the past 30 years, for example, China has taken the lead in building and putting EAST (a late-model superconducting Tokomak) into operation. That represents China's presence at the frontier of advanced nuclear fusion techniques. At the same time, China participates in the building and running of ITER, and also plays an active role to explore nuclear fusion technique both in dependence and in operation with other countries. It aims to have a thorough knowledge of this technique.

4.10.2 Key Science and Technology Issues

(1) Ocean Power Generation

The first problem is about environment involved tidal energy. To increase the conversion efficiency and reduce the building cost, efforts should be made to improve the techniques including full breaking-through hydraulic turbine technique, optimization of operation, low-cost building technique, navigation lock technique, fishes' migration-channels building technique and more advanced tidal energy techniques. The second problem lies in the high cost of wave energy. To drive the cost down, the reliability, efficiency and corrosion-proof capacity of devices should be improved. When those improved devices are put into mass production, cost will be lowered with no doubt. Wave energy techniques should also be improved to be highly efficient, anti-typhoon and cheaper. Those techniques include highly active capture technique, power uptake technique, anti-typhoon technique, corrosion protection technique, intellectual wave power energy technique and the technique of low-cost building. Thirdly, similarly with wave energy, utilization of tidal energy is also facing the problem of high cost. To put it into mass production, progress should be made in terms of reliability, efficiency and corrosion-proof capacity of devices. Tidal energy techniques should also be improved to be highly efficient, anti-typhoon and cheaper which include anti-water technique, corrosion protection technique, varying load technique, maximum capture technique and the technique of low-cost building.

(2) New-concept Solar Cell

There's a need to set the goal of concept innovation and intellectual property rights and to improve research with new concept on solar cells and related materials. Efforts should be particularly made to design and prepare multi-spectrum-band composite materials, new-concept solar cells based on nano-materials and organic-materials. To develop the new-concept solar PV technology, we need to optimize the design of the new-concept solar cells, as well as the novel structures and materials, including electrode and heterogeneous nanocrystalline. Therefore, we need to develop relevant elements, study new techniques of preparation and improve assembly technology.

There are three aspects involved in the design of new-concept solar cells. The first one is the new structure of solar cells. For example, highly-efficient AlGaAs/GaAs tandem solar cell needs to be improved in its radioprotective structure. The second one is to make full use of the panchromatic solar spectrum. One of the examples is full spectral tandem InGaN solar cell. The third aspect is to design nanocrystalline solar cell with quantum-structure and quantum-effect, utilize techniques of both nanocrystalline and nano, assemble nanocrystalline solar cell with wide spectral response band and make use of ordered low dimensional nano-materials. In terms of new-concept nanocrystalline cell, the hetero junction's mechanism and structure should be studied on atomic or molecular level.

(3) Nuclear Fusion

In the development of nuclear fusion of 50 years, the continuous operation of plasma hasn't be completely solved. Followings are some other remained problems: how to take advantage of the ITER plan as a platform to research in the balance of ion, the control over ion, the instabilities of magneto fluid, the limitations and transportation, the interaction between plasma and wave, interaction between plasma and the first wall, the integration of high-performance steadily burning plasma and energetic particle physics; how to develop the superconducting magnetism Nb_3Sn, the first wall materials, tritium techniques, long-distance control, high-efficiency and neutron-injection in stable state, the heating of micro-wave, advanced diagnose, "continuously burning", the closed circulation and self-sustaining of tritium, lightly-activated and radiation-proof materials, remote handling and other key techniques.

4.10.3 Science and Technology Objectives at Different Time Nodes

(1) Ocean Power Generation

From 2008 to 2020: ① to improve the full breaking-through hydraulic turbine technique, optimize the operation technique, lower the cost of building, develop the techniques of navigation lock and fishes migration, build an experimental tidal energy plant of 200,000 kW and to accumulate experience from long-term operations for further improvement; ② to develop both second-generation low-cost wave energy devices and wave devices for special usage of 20,000 kW in total; ③ to build high-efficient and anti-typhoon tidal power generation devices with installed gross capacity of 20,000 kW.

From 2021 to 2035: ① to build low-cost and environmentally-friendly tidal power plants of 800,000 kW; ② to maturate low-cost wave energy techniques and put forward theories of efficiency increase for the third generation of wave energy development and to have the total installed gross capacity of 100 kW; ③ to develop the tidal power generation devices in a medium scale and to have the total installed gross capacity of 800,000 kW.

From 2035 to 2050: ① to build tidal power plant of 4,000,000 kW; ② to promote maturation of the third-generation wave energy techniques of high efficiency and to put it into mass production (5,000,000 kW) in order to drive the cost down in a large margin; ③ to develop tidal power generation devices in a large scale to reach a total installed gross capacity of 2,000,000 kW and to demonstrate the commercial operation in a relatively large scale; ④ to continue the exploration on thermal energy and salinity energy.

(2) New-concept Solar Cells

Because of the complexity of this concept, time from 2008 to 2020 will be mainly spent on design and technique research. It is expected to break through the key techniques and undertake the pilot run during the period from 2020 to 2035. By the year of 2050, scale commercial applications of the new-concept solar cells will be put into practice.

(3) Nuclear Fusion

From 2008 to 2020: ① aimed at the international advanced level, to corporate broadly with other countries and establish experiment bases for magnetic confinement fusion plasma of stable state, and to explore the basic physical and engineering problems for the future nuclear reactor which is to be stable, high efficiency, safe and practical; ② to take an active part in the engineering construction of ITER and to innovate in fusion key techniques after the process of digest, absorb and master.

From 2021 to 2035: to build China's own stable-state and multi-functional

Tokomak mixed experimental reactor, particularly to develop the techniques of the advanced operation model of "continuously burning", the closed circulation and self-sustaining of tritium, the lightly-activated and radiation-proof materials, and the long-distance control.

From 2035 to 2050: to undertake the design, construction and pilot operation of the demonstrated commercial reaction of nuclear fusion.

Generation of Ocean Energy

(1) Tidal Power Station

Rance Tidal Power Station, France, the world's first large tidal power station, was put into commercial operation in 1967. The station has a total installed capacity of 240 MW, a runner diameter of 5.34 m, with 5.6 m rated head, and an annual energy output of 540 million kW·h. The station adopts the Single-reservoir Bidirectional generating pattern equipped with Bulb Type Turbine Generator which enables outlet and suction and forward-backward power generation. In this way, tidal energy utilization efficiency is enhanced while bringing the cost down.

Jiangxia Tidal Testing Hydropower Station built in 1974, is able to generate, enclose lake for land reclamation, develop marine culture and tourism, and other multipurpose utilization. It is the world's third largest tidal power station. In May, 1980, the first 500 kW unit was put into operation. The second unit has a capacity of 600 kW, and the other 4 units of 700 kW respectively. By the end of 2007, all six units were put into operation, with a total installed capacity of 3900 kW.

(2) Tidal Current Station

Horizontal Axis Turbines, MCT (Marine Current Turbines) Company, England, divided the tidal current energy into two stages. The first stage "SeaFlow", installed a 300 kW Periodflow marine current propeller type turbine, as a demonstration unit. The second stage "SeaGen", installed two 500 kW turbines on both sides of the frame to test the 2×500 kW double-units working condition in 2005.

70 kW "Wanxiang I" developed by Harbin Engineering University, operated an offshore test in Guishan Channel, Daishan, Zhejiang Province, 2002. The station adopts the Floating Vertical Axis, with a double duck heads type ship and an adjustable prismatic blade orbit spinner motor; the output end of the main shaft is installed with hydraulic and control system to control output speed. The generator is controlled by storage batteries and Grid-Connection, equipped with related protection.

(3) Ocean Wave Energy

Pelamis wave power device developed by OPD (Ocean Power Delivery Ltd.) is a revised catamaran wave power device, the energy collection system of which is buoys with 3.5 m diameter and articulated ends. By using the angular displacement of the neighboring buoys to drive the piston, the wave energy is transformed into hydraulic energy. The device consists of three parts, the installed capacity of which is 250 kW respectively, total capacity of 750 kW, stretching for 150 m on the surface of ocean with a depth of 50—60 m. This device is the world's first floating wave power station in commercial use. The Onshore Stationary Oscillation Buoy

Wave Generator and Desalination Device developed by Guangzhou Institute of Energy, Chinese Academy of Sciences, has adopted the pressure-maintaining storage technique and variable damp technique, reaching a conversion rate of 40%, which converts the captured wave directly into stable power. The rest of the energy could be utilized in seawater desalination. Thus, the stable output of wave power is guaranteed. The independent and steady generation of wave energy fuels the development of ocean and coastal defense.

(4) Thermal Energy

The Thermal Power Station developed by PICHTR began the open recycle production experiment In Nov,1991. Accomplished in April, 1993, with a 210 kW generated power, apart from the system's own energy consumption, the energy output reaches 40—50 kW, and desalinates water. PICHTR also develops a thermal utilization system, which can not only generate, but also produce desalinated water, air-conditioning, and enhanced mariculture. This system has a promising market performance.

Source: Shen Zhuyi. 1997. Tidal power station. Beijing: China Electric Power Press

4.10.4 Science and Technology Development Roadmap

Science and technology development roadmap for potential energy technology is shown in Fig.4.10.

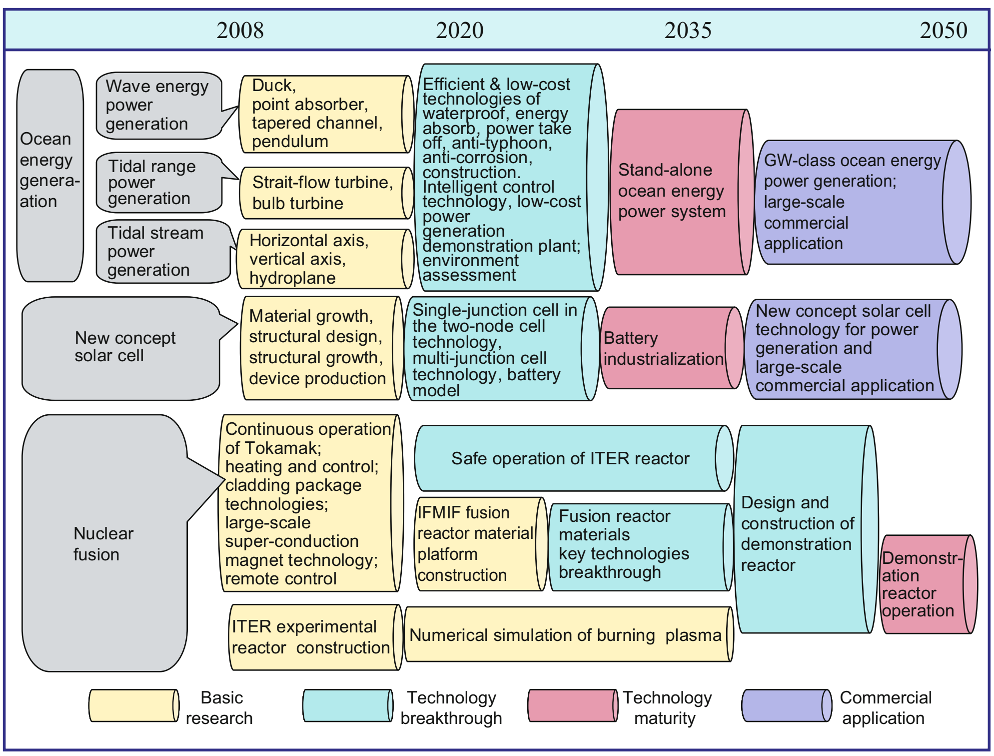


Fig. 4.10 The potential energy technology roadmap

5 General Deployment of Innovative Energy Science & Technology in China to 2050

5.1 General Deployment of China's Innovative Energy Science & Technology

Great effort should be made to break through key technological barriers, and to advance relevant technology integration, test demonstration and commercialized application. The concrete strategic steps are as follows.

By around 2020, breakthroughs should be made in clean coal technology to establish an industrial system for coal-based energy and chemical engineering, in rail transportation technology and advanced electric vehicles technology to establish a system of commercialized use of electric transportation. While taking the full use of the existing advanced hydropower and EHV power grid, breakthroughs should be made in solar thermal power, solar PV power and wind power generation technology, in order to set up a technological and industrial system with renewable energy as a major source.

By around 2035, breakthroughs in the technology of biomass to liquid fuels should be made and applied to commercial use. Based on the breakthroughs in high-capacity low-loss electric power transmission technology, scattered, unstable renewable energy grid-connected power generation and distributed grid technology, the share of power equipment security protection technology and new grid security protection technology will reach 90%. A new, distributed and independent micro-grid power system with solar power and wind power generation will be initially established. And breakthroughs in the key technology of new nuclear power generation and nuclear waste processing should be made to establish an advanced nuclear power industrial system with Chinese characteristics.

By around 2050, breakthroughs in the technology of natural gas hydrate, hydrogen, fuel cell car, deep geothermal power and ocean energy generation should be made in order to shape a diversified energy mix including fossil energy, renewable energy, and nuclear power, and thus establish an innovation based energy industry system with Chinese characteristics (Fig. 5.1).

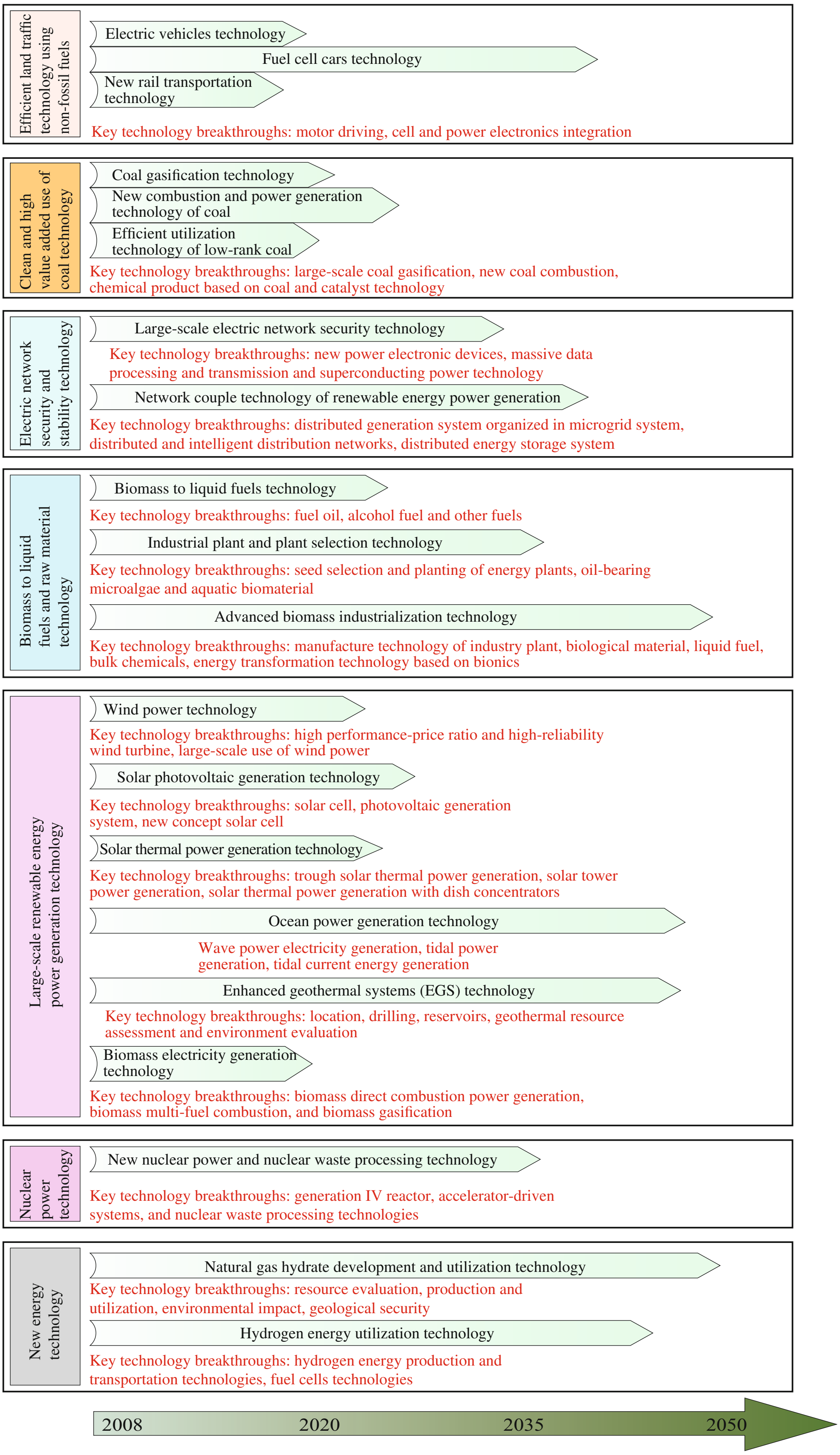


Fig. 5.1 Innovative energy technology roadmap to 2050
(Time in the figure means the large-scale commercial application time of the technology)

Through the establishment of new energy industry system with Chinese characteristics and a significantly drop in the consumption of fossil energy, carbon dioxide emission can be greatly reduced.

Energy Science and Technology Development Course of National Medium and Long Term S&T Scheme and Plan

The Outlined Plan for China's Mid- and Long-term Science and Technology Development (2006–2020) has put forward the following development courses in four areas in terms of development idea, priority theme, advanced energy technique, and frontier technology.

Firstly, our development idea is to embrace energy conservation and energy consumption reduction. We must resolve the obstacles in key energy-saving technology in main energy-consuming area, develop building energy saving technologies, and improve efficiency of primary energy and final energy consumption. Energy structure diversification should be promoted and energy supply will be increased. Oil and gas exploitation technology, water conservancy, and hydropower technology are supposed to be improved while nuclear power technology should be facilitated, so that we can boast the independent development ability of nuclear power system technology. Renewable energy technology, for example, wind power, solar power, biomass, can be put into commercial application. Clean and highly efficient use of coal should be intensified to reduce environmental pollution. We must develop technique of coal clean and highly-efficient exploitation and utilization to reach international advanced level. Digest, absorbance and re-innovation of energy equipment induction should be enhanced. The key technologies of major equipment manufacturing of coal electricity and nuclear power should be advanced. Technical ability of resources optimal allocation should be refined. We are supposed to emphasize on secure, reliable, and advanced technology of large-capacity, long-distance and high-efficiency electricity power transmission and distribution.

Secondly, priority theme includes industry energy saving, coal clean and efficient exploitation and utilization, gasification and poly-generation technologies, oil and gas exploration and exploitation in complicated geological condition, large-scale & low-cost development and utilization of renewable energy, large-scale power transmission and distribution and power grid security safeguard.

Thirdly, advanced energy technology is moving ahead in the direction of economic, high-efficiency, clean use and new energy exploitation. The development of the fourth generation technologies of nuclear system, advanced nuclear fuel recycle and nuclear fusion is drawing more and more attention. Hydrogen will bring the reform to clean use of energy as an ideal carrier which is available from different ways. The clean and flexible fuel cell power and distributed power supply system will provide new important ways for final energy utilization. Key researches is on large-scale hydrogen application, distributed power supply system, advanced recycle technology of nuclear power and nuclear fuel, clean, efficient and zero CO_2 emission fossil energy development, and low-cost&high-efficiency renewable energy technology.

Fourthly, frontier technologies include hydrogen and fuel cell technology, distributed power supply technology, fast neutron reactor technology, and magnetic confinement nuclear fusion.

Source: The people's Republic of China State Council, 2006-02-09. National long-term science and technology development plan(2006-2020). http://www.gov.cn/jrzg/2006-02/09/content_183787.htm

5.2 Time Sequence of Energy Technology Application in China

Energy lays a solid material foundation of sustainability and development of human society, and China's socio-economic sustainable development is relied on the protection of energy. Development of energy technology meets the growing demand of socio-economic development which significantly fuels the changes in energy technology. Table 5.1 demonstrates energy application technology supporting socio-economic development in different periods before 2050.

From now to 2020, our goal is to achieve large-scale application, improvement and integration of technology while technology developed in last century or at the beginning of this century gradually will be mature enough to put into commercial application. For instance, high-speed railway system, hybrid electric vehicle, coal-based/biomass-based alternative fuel vehicle, new energy-efficient materials, IGCC, EHV and UHV technology, crystalline silicon solar energy generation technology, maritime and land-based wind power technology, power-generation technology with biological substances and biomass liquid fuel technology.

From 2021 to 2035, a batch of advanced energy technology will come into commercial application on basis of studies and key technology breakthroughs achieved from 2008 to 2020. At the same time, part of energy industry with independent property rights will be set up, including electric vehicle, fuel cell vehicle, carbon-hydrogen ratio adjustable coal gasification technology, solar energy generation technology, thin film PV cell technology, the fourth generation nuclear technology and nuclear waste disposal technology, coupling technology of distributed grid.

From 2036 to 2050, scientific research achievements with independent innovation made in the early stage of the deployment will be turned into mature technology. While they are transferred into commercial application, China's independent national energy industry will be established. Development in this period includes natural gas hydrate development and utilization technology, hydrogen harness technology, application technology of super-conduct electricity, nuclear fusion, strengthened geothermal heat utilization technology, new concept technology of solar power generation, and technology of independent ocean power generation system.

Thus, new energy industry system with Chinese characteristics consisting of resources, technology, industry, market, standard and regulations will be preliminarily formed.

Table 5.1 Time sequence of China's energy technology application to 2050

		2008—2020	2021—2035	2036—2050
Energy conservation	Energy-saving industry	Energy-saving technology in key production processes; residual heat, pressure and energy utilization technology; optimized development and rational allocation technology of energy resources; high-efficiency energy conservation facility		
	Energy-saving traffic	Coal-based and biomass-based liquid fuel, fuel gas transportation, urban rail transportation, high-speed railway transportation and hybrid vehicle	*Electric vehicle *Fuel cell vehicle	
	Energy-saving building	Building wall, roof, door and window energy-saving technology, heat and air-conditioning energy-saving technology, lighting and ventilating energy-saving technology	Integrated technology of building energy-saving and environment protection	New concept building
Fossil energy	Coal	IGCC technology, supercritical technology, poly-generation technology, utilization of brown coal and other inferior coal, technology on desulfurization, denitrification, removal of heavy metal and dust and CO_2 capture technology	*Carbon-hydrogen ratio adjustable coal gasification technology	*New coal burning and power generation technology
	Oil	Oil secondary resource processing technology, oil shale utilization technology, oil sand bitumen processing technology	New technology of oil exploration and exploitation	
	Natural gas	Highly-efficiency natural gas utilization technology, natural gas distributed energy system and technology	New natural gas exploration and exploitation technology	
Electricity	Power	New technology of large power equipment, real-time simulation technology for power gird	*Technologies for the reliable operation of power grid *Coupling technology of renewable energy power generation grid	*Large-scale power storage technology *Superconducting power technology

(Continued)

		2008—2020	2021—2035	2036—2050
Nuclear energy	Nuclear power	The second and the third generation nuclear power technology	*The fourth generation nuclear power technology *Nuclear waste disposal technology	*Nuclear fusion mode reactor technology
Renewable energy	Solar energy	Active solar energy utilization, passive solar energy heat utilization, solar water heater	*Solar thermal power technology and system	Space solar energy generation
	Solar PV	Amorphous, monocrystalline and multicrystalline silicon solar cell	*Thin film PV cell technology	*New concept solar energy
	Wind power	*5MW wind power technology, ground wind power generation	*High cost-performance, high dependability wind power generator technology	
	Biomass energy	Biomass fuel in rural areas (methane, solid fuel), the first generation biomass fuel(biomass power generation, fuel ethane, bio-diesel)applied commercial, biomass material production, etc.	*Biomass alternative oil technology (biomass liquid fuel, biomass-based material, biomass-based commodity chemicals)	*Energy plants, oil-bearing micro-organism energy development on large scale *Algae utilization technology
	Geothermal energy	High, medium and low temperature geothermal power generation, heat pump, cascaded utilization of geothermal energy	*Breakthrough in enhanced geothermal systems technology	*Comercialization of enhanced geothermal systems technology
	Ocean power		*Commercial demonstration system of independent ocean power generation	*Large-scale independent ocean power generation technology
New energy	Hydrogen		*Hydrogen utilization technology	*Fuel cell technology, large-scale hydrogen power generation
	Natural gas hydrate		*Seafloor natural gas hydrate development and harness technology	*Permafrost region natural gas exploration technology

Note: Those marked with "*"refer to the selected innovation technology in this report which should be attached great importance to research and development to 2050.

6 Support System of China's Energy Science & Technology Roadmap to 2050

Energy technology has features of cross discipline, long cycle and big inertia, therefore, the achievement of roadmap relies on great progresses on time sequence, deployment of key areas, linkage between fundamental theory and technology application, and coordinative development between technological competitiveness and manufacturing industry. To ensure remarkable achievements, China must fully arouse the initiatives and creativities, promote high efficient allocation and integration of energy technology resources in the whole society and establish an energy innovation system with enterprises as its mainstay which combined with production, education and research, to improve the capability of China's independent energy innovation. China needs to strengthen its formulation of policies, regulations standards, and research, to strengthen platform of personnel, science and technology, as well as to facilitate protection of investment measures, and to promote energy technology development and innovative security system.

(1) China's Energy Development Must Meet the Demand of Energy Industry Development As Soon As Possible

China's rapid economic growth leads to continuous increase of energy demand and constant expansion of output capacity of energy supply. However, the majority of China's core energy technology and equipment are largely dependent on foreign countries. Such problem has emerged in fossil energy and potential for renewable energy. In order to solve this problem and support the development of energy industry, China must seek truth from facts by making strategic plan and resources deployment for energy technology development. Some energy technologies with no possibility to reach the international top level should be put on the road of introduction-digestion-absorbance-reinnovation. For those advanced technical courses in the process of R&D at home and abroad, China should make breakthroughs on the key science problems and tap key technology to improve their competitiveness. As for the new areas with huge potential for development, China should explore new theories, new methods and new technologies. Therefore, a energy technology system will be set up, which can support China's energy industry and lead the world through decades of unremitting efforts.

(2) Resources Investments Should Reflect the Encouragement on National Energy Industry Development

As a developing country, China can not ignore that its fiscal resources are finite. Hence, its investment on energy will be made after cautiously weighing and deploying on resources, market, industry and national security. Fiscal investment should move to upstream of industry chain. Priority and supports should be given to energy technology research and development which can expand domestic energy market and promote development of energy equipment manufacturing industry. These supportive efforts include huge investment on new solar PV energy generation technology and heat generation technology, reversing the passive situation that PV industry has fallen behind other industry, investing heavily on grid and distributed grid technology and R&D equipment to maintain China's advantage position in large-scale power generation and power transmission technology.

(3) Keep up with the Trend on Training and Education System for Energy Science and Technology Talents

With the development of renewable energy and nuclear power, current fossil-energy based nurturing and education system for energy technology talents cannot meet the demand for renewable energy. Therefore, cross-discipline integration is needed. Catalytic technology in chemical engineering, fluid machinery of mechanical engineering, optical technique, biochemical technique, and even gene technology and synthetic technology are now being widely used in energy sector. Current energy technology has been no longer the conventional "Heat Science and Technology". People have come up with synthetic fuel, breeding fuel and enriched fuel instead of directly using energy. Hence, traditional nurturing and education system of energy talents should be reformed. Task of energy development in the near future is arduous, and building a scientific and innovative energy talents nurturing and education system is very crucial to China's energy development.

(4) The Establishment of A Specialized Nuclear Power Technology Institute of Chinese Academy of Sciences is in Urgent Need

It is necessary to build a strong nuclear industry in China as a big country for its needs of politics, national defense and national security. Despite a sound momentum of growth, the current nuclear industry in China still remains relatively small sized, slowly developing and enjoys unsatisfactory autonomy which hampers the development of its nuclear industry. To improve the self-innovation in this industry, China should construct a solid base of nuclear science research and nuclear technology education for the training of talents, mastery of key technology and the development of its own nuclear equipment industry. At present the main force of nuclear power design and operation consists mainly of China National Nuclear Corporation and China Guangdong Nuclear Hold Corporation. State Nuclear Power Technology Corporation, which was a joint venture supported by the State Council, China National Nuclear Corporation, China Power Investment Corporation, China Guangdong Nuclear Hold Corporation, China National Import and Export Corporation in May 2007, is in charge of introduction, digestion, absorption and re-innovation of the third generation nuclear power technology. The Chinese Academy of Sciences, considerably developed in nucleosynthesis, nuclear waste management and hybrid reactor technology, has signed a framework agreement of technology collaboration with China Guangdong Nuclear Hold Corporation, to promote solid cooperation with major nuclear power enterprises for the construction of a research center and enhance CAS' design and research capacity in the basic theories and core technologies of the new generation of nuclear power technology and nuclear waste management.

(5) Development and Innovation of New Theories and New Methods in Energy Science

In the coming decades the dominant energy resources may comprise the new varieties characterized by "carbon-free", "low-carbon", "hydrogen-rich", etc., such as renewable energy, new energy and so on. The conversion process of some of those energy resources is fundamentally different from that of fossil energy which is thermal reaction despite the terminal energy resource as "heat, electricity and petroleum". For example, wind power generation, ocean power generation and hydroelectric power provide ways to convert mechanical energy into electrical energy while PV power utilizes the dielectric nature of substances and some other forms of conversion imitate bionic process. Fossil energy technology in China has limited potential for innovation whereas large potential lies in the area of non-conventional energy. Therefore China's status in the energy science and technology should be raised through encouraging more innovative academic theories and research methods in the areas of energy resources attribute, energy conversion laws, energy release control, etc., which share certain characteristics.

(6) Construct International Advanced Energy Science and Technology Innovation Group

A number of state key laboratories have been set up in China in the energy sector based on the exploration and utilization of coal. Despite that science and research have been improved, an internationally leading, predominant and irreplaceable R&D platforms or groups have not yet been found in fields like clean energy, renewable energy, new energy, nuclear energy, and hydrogen energy utilization. In order to achieve the goals at different intervals in this roadmap of energy science and technology, the layout and construction should be strengthened in energy science and technology power and research facilities. Some of the strategies that could be adopted are as follows. Firstly, the international direction of development should be clear, which means that the increasingly internationalized resources, technology, information and market should be faced. Secondly, fundamental study of energy and R&D of generic technology should be strengthened, and researchers should focus on durability and influence of sci-tech output. Thirdly, the functions of sci-tech innovation should have striking features in the areas of fundamental research, technology R&D, engineering designing, and equipment manufacturing and so forth. To cover the entire industry chain is unnecessary, but it is conducive for rational allocation of resources and optimization of labor division. Fourthly, China should build large and sound energy equipments, for example, hydrate simulated formation and large exploitation platform, energy transformation in extreme condition and on-line testing platform in order to improve national energy output quality and R&D standard. Fifthly, efforts should be made to encourage scientific research institutes, universities and colleges as well as oversea R&D institution, to set up joint lab or R&D center to carry out international cooperative project under bilateral and multilateral sci-tech cooperation framework, to improve R&D capacity and cultivate high-level energy talent force with world foresight and world leading research ability.

(7) Continue High-quality Energy Strategy and Energy Sci-tech Policies Study

China should establish macro coordinative mechanism of national energy science and technology and maintain the basic status of sci-tech policy as national public policy. In pursuit of promoting sci-tech innovation and strengthening independent innovation ability, policy system of coordinative interaction between national energy sci-tech policy and economic policy should be established. Promotion should be made to reform of energy technology management system with scientific, foresighted and enduring energy strategy research as basis of national energy plan formulation and improvement of sci-tech decision making mechanism. Mechanism obstacles must be eliminated and coordination of department-department, region-region, department-region and army-people should be strengthened. Ability of integrating sci-tech resources and organizing significant sci-tech events should be improved practically to ensure energy technology cooperation.

In order to ensure sustainability of study, the roadmap is supposed to be upgraded and optimized every three or five years. Then the roadmap can reflect scientific development tendency and guide direction of energy technology development.

References

[1] European Renewable Energy Council. Renewable Energy Technology Roadmap Up to 2020. 2007, http://www.erec.org.

[2] United States Department of Energy. National Hydrogen Energy Roadmap.2002. http://www.eren.doe.gov/hydrogen.

[3] Renewable Vision 2020 Executive Steering Group. The Technology Roadmap for Plant//Crop-Based Renewable Resources 2020.1999, http://www.oit.doe.gov/agriculture.

[4] Agency for Natural Resources and Energy. Energy Technology Strategy (Technology Strategy Map 2007), 2007. http://www.iae.or.jp/etm.htm.

[5] Ministry of Economy, Trade and Industry in Japan. Strategic Technology Roadmap in Energy Field—Energy Technology Vision 2100-. 2006, http://www.iae.or.jp/etm.html.

[6] U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum. Technology Roadmap for Generation IV Nuclear Energy Systems. December 2002, http://www.ne.doe.gov/genIV/documents/gen_iv_roadmap.pdf.

[7] International Energy Agency. Energy Technology Perspectives 2008: Scenarios & Strategies to 2050. http://www.iea.org/textbase/publications/..OECD/IEA, 2008, Paris, France.

[8] Ministry of Environmental Protection. China Environment Bulletin 2007. 2008, http://www.mep.gov.cn/plan/zkgb/2007zkgb/.

[9] Intergovernmental Panel on Climate Change .IPCC Fourth Assessment Report—Climate Change 2007: Synthesis Report. 2007, http://www.ipcc.ch/ipccreports/ar4-syr.htm.

[10] National Development and Reform Commission. China's National Climate Change Policy. 2007, http://www.mep.gov.cn/plan/zkgb/2007zkgb/ .

[11] Lu Yongxiang etc. Suggested Strategies of China's Sustainable Energy System Development During Half of the Twenty-first Century (discussion paper). Academic Divisions of CAS. 2007.

[12] International Energy Agency(IEA). World Energy Outlook 2007—China Insight.2008, http://www.worldenergyoutlook.com/index_chinese. asp.

[13] The Energy Data and Modeling Center, The Institute of Energy Economics, Japan. 2008 Handbook of Energy & Economic Statistics in Japan. The Energy Conservation Center, JANPAN, 2008.

Epilogue

China has a huge demand for energy. *Energy Science & Technology in China: A Roadmap to 2050* understands the characteristics of the energy technologies well, analyses the world's energy situation, and outlines 10 major cutting-edge technologies for development of energy science and new national energy industry in order to meet the needs of economic and social development. These are the highly-efficient non-fossil-fuel ground transportation technology, the clean and high-added-value coal utilization technology, the power system security and stability technology, the biomass liquid fuel and raw material technology ,large-scale power generation technology from renewable energy resources , enhanced geothermal systems technology for deep geothermal resources, hydrogen utilization technology, natural gas hydrate's development and utilization of technology, the new nuclear power and nuclear waste treatment technology, and the potential energy technology.

To finish this roadmap, we carried on heated discussion and debates in order to choose right technical direction of roadmap. We summarized some of the arguments and suggestions for consideration and further discussion.

(1) About the Prediction of Energy Demand in Future

The roadmap should be closely related with China's national conditions, socio-economic development and national strategy. The development of energy ought to be sustainable, so it's necessary to predict China's future on energy demand. In this project, we analyzed the possible situation raised in modernization, such as socio-economic development, the bottleneck of energy development and environmental capacity constraints. Based on this, we predicted that China's total energy demand will reach 3.1, 4.5, 6.1, and 6.6 billion tce in 2010, 2020, 2035, and 2050 respectively, different with other prediction at home and abroad. For example, Academic Division of Chinese Academy of Sciences predicted that by 2050 China's total energy consumption will stand at 5 billion tce; by 2030 it will be 6.7 billion tce according to high growth scenario of International Energy Agency; Green Peace & the European Renewable Energy Council forecast that China's total energy consumption will be only 4.4 billion tce by 2050.

(2) About the Solution to Decease Carbon Dioxide's Impact on Environment

Global climate change caused by greenhouse gas emissions has attached great concern. According to this report, by 2050, China's per capita CO_2

emissions will be lower than that of North America, Europe and Japan, but total emission will be higher than these countries and regions. As a large responsible country, China would like to cooperate with international community to develop advanced technology and countermeasures to reduce emission of greenhouse gas and to mitigate climate change.

Some experts believe that coal will still be the major source of energy for many years. To decrease emission, we have to pay more attention to carbon dioxide capture and storage (CCS). Some experts maintain that we should vigorously develop new and renewable energy to reduce fossil energy consumption, cut down carbon emission from the source or by changing the utilization pattern and coal-burning technology, such as chemical chain combustion, pure oxygen combustion, industrial technology of coal-based chemicals. We should also aim at reducing carbon dioxide levels in the smoke or fix carbon in converted material.

(3) About Coal-based Chemical Technology

Coal is characterized by polymer and macromolecules of the chemical structure. Some experts claim to use coal as chemical resources rather than energy. With scientific and technological progress, coal could be captured by biological, chemical, physical way from chemical substances. On one hand, it can improve added value of coal. On the other hand, it can store principal elements, namely carbon, sulfur, nitrogen, in organic chemical products. The study of directional extraction approach of coal-based chemicals was started since the 1950s, but has yet to make great breakthroughs, because it's hard to get pure chemicals among numerous and complicated chemicals.

(4) About Development Direction of Biomass Energy Utilization Technology

Biomass is the only renewable energy which can be converted into gaseous, liquid and solid energy and chemical raw material. Several key biomass energy utilization technologies are put into application, such as combustion technology for power generation, fuel ethanol by biomass fermentation, alcohol ether production by thermo-chemical approach. As we can see, biomass utilization technologies have been diversified and upgraded in recent years. However, the use of biomass arouses a lot of controversy. Some experts believe it couldn't reduce the carbon emission at a certain time and space (though there are zero emissions in carbon dioxide theoretically).So we need to change them into bulk chemicals instead of using as energy. In this way, it can replace oil indirectly and store carbon of biomass in converted material. Others maintain that the use of biomass should be phased. In recent period, methane and power generation are paramount, while in the medium-term, we give priority to make liquid fuel. In long-term, we will pay equal attention to producing bulk chemicals and developing aquatic substances. In the spirit of "not occupy farmland and grain", some experts believe that we should use biomass cautiously. While some experts believe that technology should not be restricted by these principles since energy is not mere economic resource, but political and strategic resource as well so that we need to have more technical reserves in order to meet the needs of national security.

(5) About the Development and Application of Natural Gas Hydrates

China is the fourth country which collected the physical samples of natural gas hydrate, following by the United States, Japan, and India. This action has proved existence of gas hydrates in China and marked improvement of China's production technique and scientific strength. However, we have yet to see a full picture of quantity, and distribution characters of gas hydrates. And we just wonder whether there are gas hydrates in permafrost. Many experts are still discussing problems like how to do research and development, when the gas hydrate will become major energy, how it can affect environment.

(6) About Hydrogen Energy

The U.S. is the first country which came up with the strategic vision of hydrogen energy and hydrogen economy, setting off a new upsurge of R&D of hydrogen globally. Captured from a variety of access, hydrogen is an ideal energy to help fossil energy's transition to renewable energy. With clean and flexible fuel cells and distributed energy supply system, hydrogen will set a good example for new end-energy utilization. However, hydrogen is secondary energy derived from other substances. It tends to consume more energy for hydrogen production and storage. Therefore, some people are still suspecting and hesitating to develop hydrogen energy technology.

(7) About Solar Power Technology

Silicon-based photovoltaic (PV) solar energy technologies and PV industry have yielded substantial results. Although the cost performance of PV technology is too high to come to large-scale commercial use. Therefore, some experts suggested that researchers should speed up R&D of silicon-based tandem thin film solar cells, dye-sensitized solar cells, cadmium telluride solar cells, concentrator solar cells and copper indium gallium selenium (CIGS) thin film solar cells, aiming at raising conversion efficiency of PV cells and drive costs down. While other experts believe that the current production of solar cells have led to over-consumption of energy, material, money and generated pollution as well. In their opinion, silicon-based solar cells development should be limited on one hand. On the other hand, new principles and methods study of solar energy conversion will be intensified as well in order to make new technology breakthroughs. Some experts consider that large-scale solar thermal power technology is extremely urgent, once great breakthroughs in high-density concentrator and efficient high-temperature heat transfer working substance are achieved, large-scale solar thermal power can come to large-scale commercial use.

(8) About Nuclear Power

Experts agreed to develop nuclear technology but diverged on how to choose a technology road. Some experts think we should speed up research and development of fusion energy, making it become the major energy by the middle of this century. While some experts consider that fusion energy will come to large-scale commercial use until the end of this century because there are too many difficulties to be resolved. Therefore efforts should be made on introduction and application of third-generation nuclear power technology, focusing on developing fourth and following generation independent innovation to meet the international standard, forming nuclear power industry with Chinese characteristics.

(9) About Utilization of Geothermal Energy

The earth has abundant geothermal resources. Up to now, a few hundred meters of geothermal resources in surface have been used by human beings. Heat utilization technology is especially mature, but it is hard to make a great contribution because of low grade and low energy density. They have yet to become major energy for many years. However, some experts believe that we should speed up the development and utilization of the deep geothermal resources which are bountiful and have great potential to become a safe, reliable major energy.

Owing to all the study group members' hardworking, it took more than one year to finish this roadmap. In this endeavor, we faced a lot of difficulties, such as wide energy disciplines involved, complex technology systems, policy affection, long time span, our limited expertise and knowledge, which make the roadmap far from perfect. We are open to different criticism from different people. Let's make joint efforts to facilitate China's energy industry with good knowledge of cutting-edges scientific, forward-looking energy technology.

Research Group on Energy of the Chinese Academy of Sciences

April, 2009