Proceedings of the 2nd IAEA Technical Meeting on First Generation of Fusion Power Plants: Design & Technology

Energy Demand and Possible Strategy of Fusion Research in China

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Abstract: China, presently the country with the world's largest population will face serious pollution problems and shortage of energy in the near future to face the foreseen rapid social-economic development. Fossil fuels (coal, gas and oils) will be the main energy resources responsible for serious pollution and environmental problems in the long term. The energy development strategy recently declared by the government include: 1) develop the technologies for high efficiency, / low pollution utilization of fossil fuel, especially coal, the development of clean and renewable energy such as hydrodynamic, solar, wind and biomass will be strongly supported; 2) the fission power will be developed as far as possible in next 10 to 40 years. Rapid development of fission power will pose a new and serious problem for China namely, shortage of the natural uranium ore and large amounts of radioactive wastes with long half-lives to deal with; 3) Therefore, China must support fusion energy development as much as possible from now. The possible strategy for fusion research in China is: strengthen the support for EAST to achieve its scientific missions as soon as possible and support ITER activities on the joint design, construction, assembly and burning plasma experiments; to begin the conceptual and engineering design of the test fusion reactor as soon as possible and promote construction of the test reactor due to be constructed around 2020~2030. Several conceptual designs of test reactors with different blankets have been proposed. It is hoped that the first fusion power plant will be constructed around 2040~2050.

1. Serious energy problem [1] [2]

1.1 The population in China is currently around 1.3 billion and still increasing. It will be 1.5~1.6 billion by 2050. Per capita data for China for GDP, energy consumption, and fossil energy resources is quite low. For instance per capita consumption of energy in China is less than 1/2 of the world average level and only 1/10 of the level of developed countries;

1.2 Coal is the major source of energy. More than 70% of the primary energy comes from coal, much higher than the 42% of the world's average. In 2007 about 2340 million ton of coal were consumed which produced 26.0 million ton of SO_2 and contributed to the pollution of approximately 70% of rivers, lakes and 1/3 area of the territory. Using large amount of fossil energy will produce large amount of CO_2 which in turn will cause serious green house effects. Developed countries produced 77% of the total CO_2 in the world from 1950 to 2000. China is currently the world's second largest producer of CO_2 and will be the first by around 2025. Of greater concern is the fact that the situation will continue for a long time if a determined effort to change is not adopted as soon as possible.

1.3 China has a large population, resulting in a low per-capita average of energy resources in the world. The per-capita average of both coal and hydropower resources is about 50% of the world's average, while the per-capita average of both oil and natural gas resources is only 1/15 of the world's average. The per-capita average of arable land is less than 30% of the world's average, which has hindered the development of biomass energy.

1.4 During the period 1980-2006, China's energy consumption increased by 5.6 % annually, boosting by 9.8 % the annual growth of the national economy. The rapid social-economic development has continued for more than 20 years. In 2006 the GDP reached 20.94 trillion Yuan (RMB) and the per-capita GDP has reached over 2000 US dollar. China is already the second largest energy producer and consumer in the world and with the implementation of the 11th Five-Year Plan, the national economy will grow further. By 2010, China's GDP will reach 26.1 trillion RMB and per capita GDP will amount to 19,270 RMB. Calculated at the current exchange rate, the GDP will then total $3.2 trillion USD and per capita GDP will be more than $2400 USD. By 2050 the total GDP will be $ 6-12 trillion USD. At that time the energy demand will be 5 billion tons of CE (in 2006 it was only 2.46 billion tons of CE) and the installed electric capacity will be 1200-1500 GW (it is currently only 129 GW). So in the near future energy consumption will increase at considerable rate. China will face serious problems in terms of energy shortage and environmental pollution resulting from energy consumption. China has the largest population, one of the fastest social economic growth rates, the largest long term consumption of fossil fuel especially coal and quite low per-capita average of energy resources . The problems will be more serious in near future. China must develop renewable energy and nuclear power as fast as possible. The need for a solution to the energy problem is not unique to China but is in fact world-wide.

2. Policies & programs announced by government recently [3] [4]

In view of the serious and important energy problem and guided by the scientific outlook on development, the government is accelerating its development of a modern energy industry. Resource conservation and environmental protection are two basic state policies, with prominence given to building a resource-conserving and environment-friendly society in the course of its industrialization and modernization. The government is striving to enhance its sustainable development capability and make China an innovative country, able to contribute to the world's economy and prosperity. Based on the above position, the following goals come from a series of national programs, plans and policies which have been established and are under implementation in recent years:

2.1 11th Five-Year Plan(2005-2010):

Special efforts will concentrate on developing clean coal and thermal-power central heating technology, improving efficiency of energy utilization, strengthening energy conservation; developing natural gas, hydraulic power, renewable energy, developing methane, solar and wind energy, reducing the proportion of coal in energy consumption in order to greatly reduce environmental pollution. The concrete goals are:

- Stop and close the smaller and low efficiency heat power plants, the total closed capability will be 50 GW. New power plants to be built should be more than 600 MW and having higher efficiencies.
- Strengthen support for all kinds of renewable energy resources;
- To control the primary energy consumption to the level of ~ 2.7 billion ton of CE per year, boosting the 7.5 % annual growth of the national economy;

- At 2010 the energy consumption per GDP should decrease by 20% and major pollution should decrease by 10% in comparison to 2005.

2.2 Medium- term (to 2020)

- The capacity of hydropower has now reached 108 GW which is 1/4 total capacity of electric power and will reach 290 GW by 2020, which is ~70% of total hydropower resources.
- Support the development of wind, solar and renewable power plants: biomass power will be 20 GW, solar ~ 2 GW, wind power 30 GW, the total of which represents 30% of total capability of power plants in 2020
- The Solar heater will be ~ 3 x 10^8 $meter^2$ and equivalent to 40 million tons of CE;
- Total renewable energy will therefore be increased from 7% to 16% in primary energy sources;
- Accelerating fission power as quickly as possible from now. Fission power will be increased from 7GW (~1.4%) to 40 GW (~4%)

2.3 Long term (-2050):

- Continue to promote the development of renewable energy such as solar, wind, biomass;
- Continue to accelerate fission power especially the fission breeding reactor in order to increase the efficiency of the utilization of Uranium ore.
- To strengthen the support and development of fusion reactors for an ultimate solution to the sustainable development of China and mankind.

3. Fission energy will develop very fast [5]

Per capita fossil fuel resources are only 56% of the world level, natural gas is 8% and even with full utilization of hydro power resources only 28% of the total electric power demands are met. Development of nuclear fission power should therefore be a priority as it will be important for control of CO_2 emissions and other pollutants on the atmosphere. The demand for nuclear power in China will be extremely large in next 20 to 40 years.

3.1 The goals of nuclear power in medium- long- term:

The national program for the medium-long-term development of nuclear power was announced last year. The concrete goals are:

- At 2010 the capacity of nuclear power will be greater than 10 GW and by 2020 it should achieve 40 GW which is equivalent to 4% of total electric capacity;
- The fast breeder plan: by 2007 complete a 65MW experimental fast breeder (electric power 20MW) and at 2015 complete a DEMO with 50~300MW power, at 2025 get a power plant with 1~1.5 GW ;
- Support the HTGR plan: one 10MW plant has been completed and is currently in operation, and another one with 200 MW will be constructed.
- In the long term (to ~ 2050) : If China can achieve the world average level of nuclear power, the table below shows three different scenarios of the demand for nuclear power in China by approximately 2050. It represents a big challenge but is necessary for the environmentally-friendly and sustainable development of China. Without this there will be serious fossil fuel shortage and pollution even if energy utilization improves significantly in the same period.

Scenario	Ratio A	Ratio B	Null. Power Capacity	(Approximate Scale)
Low Level	10%	6%	120Gw	Double in France
Mid. Level	20%	12%	240Gw	Sum in US, France and RF
High Level	30%	18%	360Gw	> Sum all over the world

Table 1: The Three Scenarios of Nuclear Power in China -A: the fraction of nuclear power in total electricity capacity; B: the fraction of nuclear power in total primary energy capacity

3.2 New problems

Following the rapid and vast development of nuclear fission power China will face new kinds of serious problems: firstly, limitations of the natural uranium ore both in China and also worldwide mean that natural U-ore can only be used for a few tens of years unless the U 238 can be bred to be the fission fuel. Breeding fission fuel will therefore be the most important basic requirement for fission energy development. Secondly the huge amount of radioactive waste with long half-lives which comes from fission reactors needs to be treated. Highly efficient transmutation of fission wastes will be another potentially serious problem.

From the point of view of solving the energy shortage and pollution problems and also from the point of view of supporting fission energy development over the same period (next 40~50 years), China must support fusion energy development more and more from now.

4 Fusion research in China [6] [7]

4.1 Institutes, facilities and organizations on fusion research

Magnetic fusion research began in 1958 in China. Since then this research has gained more and more support. The main research institutes and universities which have until now been involved in research or education for fusion are shown in Table 2. All research is supported from different channels. All fusion research units belong to the Chinese Academy of Sciences (**CAS**), or Ministry of Education **(ME)** and or Commission of Science Technology and Industry for National Defense (**CSTIND)** respectively. Each institute can obtain normal financial support from it’s managing organization and can also obtain special budgetary support for special projects via different channels such as the National Development and Reform Commission (**NDRC)**, Ministry of Science and Technology (**MST)** and National Natural Science Foundation of China (**NNSF)** and so on.

Fusion research has expanded since 1958 where it began on small to medium scale research facilities such as CT-6 in CASIPP, LH-1 in SWIP, HT-6B and HT-6M in CASIPP. At present, total manpower including physicists and engineers who work on magnetic fusion research is about 1000. Rapid development of fusion research has attracted more and more young generation students to join fusion research. More than 500 graduates are studying in ASIPP, SWIP and universities for either master or PhD. The young generation will be very important for continued rapid development of fusion research in China.

Table 2 Magnetic fusion research: Units and main facilities

The Units	Main research facility
Southwest Institute of Physics (SWIP) Chengdu, **CSTIND**	**HL2A**: B_o=2.8T, I_P=0.48MA, R_o=1.64m a=0.4 m, K_x=1-1.3(1.6-1.8),
Institute of Plasma Physics (IPP) Hefei, **CAS**	**HT-7:** R = 1.22m, a = 0.27m B_T=1~2.5T, Ip = 100~250 kA **EAST:** B_o=3.5T, I_P=1MA, R_o=1.7m a=0.4 m, K_x=1.6 – 2, d_x =0.6 - 0.8 Pulse length 1000 s
Department of Advanced Physics, Univ. of Science and Technology of China (USTC), Hefei, **ME**	**KT-5C** Tokamak
Department of Engineering and Physics, Tsinghua University, Beijing **ME**	**SUNIST** (Sino United Spherical Tokamak) R=0.3 m; a=0.23 m; A> 1.3; K ~ 1.6; B_{T0}= 0.15 T; I_p =0.05 MA
Institute for Fusion and Plasma, Huazhong University of Science and Technology Wuhan, **ME**	**J-TEXT (joint TEXT)** R=1.03 m; a=0.27 m; B_{T0}= 3.0 T; I_p =0.05 MA
Institute for Fusion Theory & Simulation, Zhejiang university, Hangzhou, **ME**	Theory & Simulation for EAST, HL2A and ITER

a) EAST superconducting Tokamak in CAS IPP

b) HL-2A Tokamak in SWIP,

Fig. 1 Main tokamak devices in China at present

At present four national projects are supported by different government channels as follows:

1) Conceptual design and some R&D of hybrid fusion reactor under the National High Tech. program (called the 863 program as it was approved in principle in March 1986) supported via **MST**; **2)** The national EAST (Experimental Advanced Superconducting Tokamak) project directly supported via **NDRC**; **3)** Join the ITER project which is under the management of and getting national support via **MST**; **4)** Continue to support the HL-2A upgrade via **CSTIND**

4.2 Possible strategy of fusion research in future [8]

In recent years the Chinese government has given strong support to fusion research both on EAST project and as a participant in ITER project. The government is encouraging and requesting wide discussion of future strategy for fusion research in China. The possible roadmap is the following:

1) All missions, especially the steady state operation with higher performance plasma on EAST (shown in Fig.1), which is the first full ITER-like SC Tokamak in the world and began operation in 2006, should be achieved within next 10 years

2) As a member of ITER, China should make great efforts towards the joint design, construction and assembly of ITER and then on the burning plasma experiments in order to contribute together with other members towards the basis for technology and physics for a future fusion reactor;

3) Using the knowledge and recommendations from progress made at EAST, ITER and other international fusion projects, China should begin the conceptual and engineering design of the test reactor as soon as possible. The test reactor must satisfy at least three goals: a) can breed fission fuel, b) can transmute large amount of long-lived wastes which come from fission reactor, c) can produce tritium for fusion fuel cycling. Important R&D into issues such as blanket and materials should also begin as early as possible. The test reactor should be constructed around 2020 ~ 2030. The test reactor must have multi-functions. Therefore the key design will be the blanket. Several conceptual designs of the test reactor and blanket have been done by the teams both in CASIPP and SWIP. [9] [10]

The test fusion reactor designs include: FDS-I: a fusion-driven sub-critical system for early application of fusion e.g. waste transmutation and fuel breeding etc; FDS-II: a fusion power reactor for advanced electricity generation; FDS-III: a high temperature fusion reactor for hydrogen generation; FDS-ST: a spherical tokamak-based reactor to exploit innovative conceptual path. Fig.2 shows the conceptual designs:

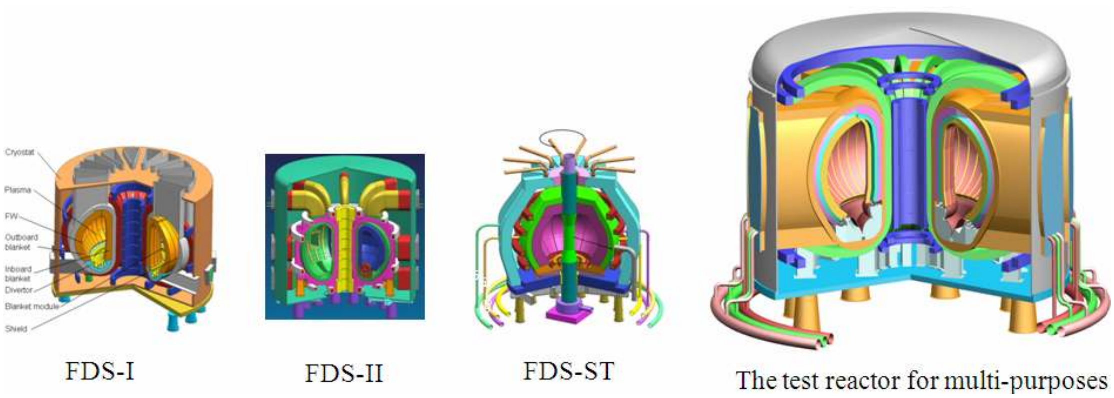

Fig.2 The conceptual designs for series test fusion reactors

The several conceptual designs of blankets for different functions include: DWT: Dual-coolant (He/LiPb) Waste Transmutation Blanket (outlet temp.<450°C); SLL: Single-coolant (He) Lithium Lead Breeder Blanket (outlet temp.~450°C); DLL: Dual-coolant (He/LiPb) Lithium-Lead Breeder Blanket (outlet temp.~700°C); HTL:

High Temperature Liquid Blanket (outlet temp.900~1000°C). More detail information can be seen in [8] [9].

By combining the FDS fusion reactor, FBR and PWR with the high efficiency of using U ore it will be possible to accelerate the fission power to achieve ~400-700GW (30% of total electricity capacity) by around 2050 in China

4) It is hoped that the first fusion power plant based on the progresses of the above phases can be constructed by around 2040~ 2050 allowing fusion energy to be used commercially in China by the middle of the century.

Summary

China is facing serious energy shortages and high pollution levels. A series of national policies, plans and programs on energy have been announced, established and implemented. They are aimed at resource-conserving, environmentally-friendly and sustainable energy development. From a medium to long-term perspective, fission power must be accelerated now followed by great effort towards fusion energy development. The strategy for fusion research in China could be: strengthen the support of existent EAST, HL-2A and ITER; begin the conceptual design and R&D of the multi-function test fusion reactor as early as possible and to get the test reactor operational by 2020~2030, then to build the first fusion power plant by around 2050.

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