UNIVERSITY OF GÄVLE

FACULTY OF ENGINEERING AND SUSTAINABLE

The Environment and Challenge of China's Energy Technology development

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Abstract

In China, the energy technology is the fundamental technology which plays a significant role in China's boost. Currently, China's energy technology is in a high-speed development and transformation period when great opportunities and challenges are existing in optimization of energy structure and new energy technology development. In this paper, the achievement the China has obtained in recent years in this area as well as the forthcoming challenges are expounded in four aspects—the basic environment of China's energy development, development of China's energy technology, challenges encountered by China's energy technology development and the system innovation in the energy technology development.

Content:

Introduction

With the rapid development of China's economy in recent years, China's need on the energy has been increasingly enlarged-both the industry and economy can't develop without the energy. Though experiencing noticeable development brought by a series of reforms including the reform and opening up, China is still a developing country which is learning from the western world in the area of energy technology. China's energy structure has been continually optimized and improved since the 1990's, but it still seems to be simplex compared with that of western countries. In recent years, the international proposed the objective of saving energy and reducing emission. As a large industrial country, China also needs to develop a much cleaner and more efficient energy model while adjusting the traditional high-consumption and high-pollution energy structure urgently. Therefore, the environment-friendly energy seems to be more and more significant.

Nowadays, China is focusing on developing hydropower source. However, considering the inevitable limitation and great ecological influence of the hydropower, the optimization of the traditional power model and the development of new energies are necessary, which are also very critical to the development of China's future economy and industry. Contributing to the status of China's energy technologies, this present paper discusses the future orientation and would-be confronted problems of China's energy technologies.

1. The basic environment of China's energy technology development

The progress of energy technology should be adaptive to the need of development of energy industry and be able to solve some problems appearing in this industry. In turn, the development condition of the energy industry also influences and constrains the development of China's energy technology, as it is the basic environment of the development of China's energy technology, divorced from which the energy technology can hardly be industrialized or boosted. It is concluded that the present development condition of China's energy industry has the following characteristics:

1.1 The overall output of the energy is increased in fluctuation and energy structure optimized, but the import dependence intends to increase

Since the 1990's, China has witness the overall output of its primary energy rise in fluctuation, with the 1048.44 million ton of coal in 1991 increasing to 2969.16 million ton of coal in 2010. As to the structure of the primary energy, the output of raw coal was 1087 million ton in 1991, which increased to 2970 million in 2009, with the proportion of 74.1% in 1991 increasing to 77.3% in 2009; besides, the output of raw oil, natural gas and hydroelectric power increased to 167 million ton, 32791 million cubic meters and 337673 KWH from 141 million ton, 16073 million cubic meters and 124700 million KWH, respectively, and their combined proportion in the total energy increased to 29.3% in 2002 from 25.9% in 1991. As far as the energy consumption structure is concerned, the oil, natural gas and hydroelectric power took 17.1％, 2％ and 4.8％ of the total energy consumption in 1999, respectively, which increased to 9.8%, 4.3% and 9.4% respectively in 2002. According to the commercial energy output (a thousand ton of oil equivalent) counted by the World Bank, China ranked the world's second, with the output being 60% of that of the USA. However, after coming into the 1990's, the gap between the energy production and consumption increased gradually year by year, as was the dependence on importation, especially in the years since 1997, when the tendency has been more and more obvious (see Table 1 for specific data).

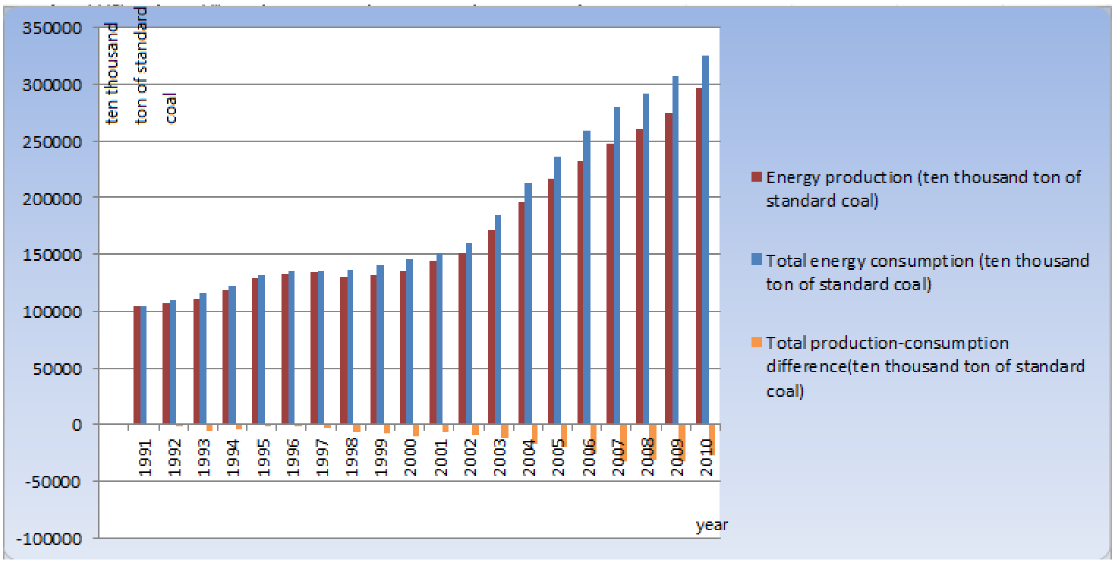

Figure 1: Difference of energy production-consumption (from table 1)

1.2 The high-energy consuming economic growth is changing, but the gap still exists

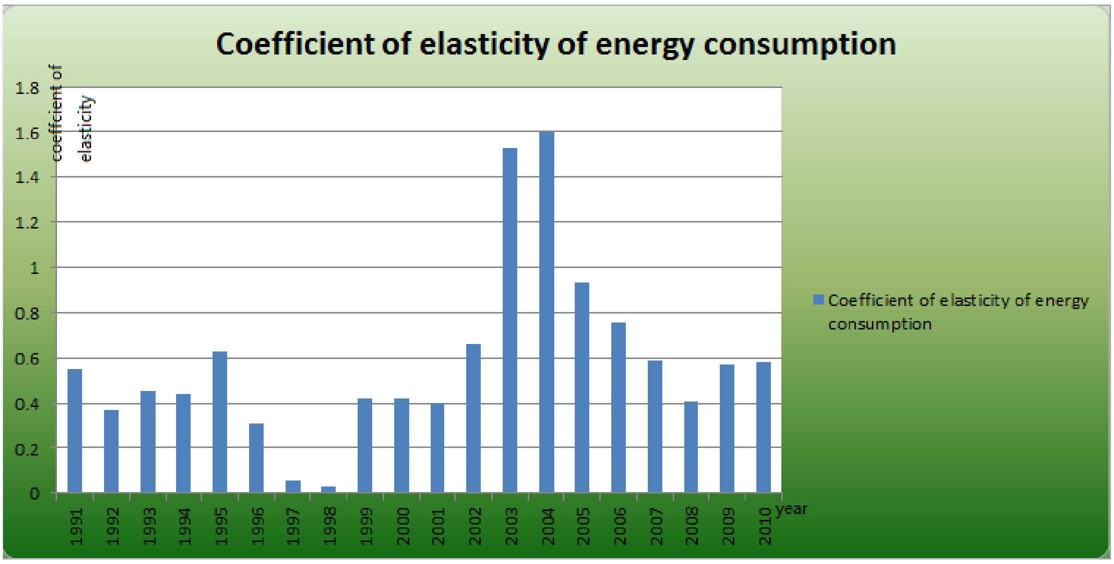

Figure 2: Coefficient of elasticity of energy consumption (from table 2)

During the period of 1991-2000, China's energy consumption elasticity almost ranged between 0.31 and 0.63; after 2005, this figure turned into negative behind it increase four consecutive years (See Table 2). This means that the growth pattern of Chinese economy was adjusted and converted, in order to change the extensive economic growth pattern characterizing heavy energy consumption and high investment. The energy conversion efficiency rose from 65.9% in 1991 to 72.01% in 2009 (see Table 4), thus providing a good foundation for realizing the objective of "quadruple leaps" (the total energy consumption will decrease to 50% of that of 2000, while GDP will be doubled) proposed the United States. However, the gap between China and developed countries in energy efficiency should also be noticed. According to the statistic of the World Bank, China's energy generated 4.0 GDP/ kg oil equivalent (calculated at the PPP price), only the average level of mid-income countries, while the figure in European Union was 5.6 dollars/ kg oil equivalent and Japan 6.0 dollars, even in some developing countries, such as India (4.3 dollars) and Brazil (6.5 dollars), the figure was higher than China that time. Therefore, it is a big challenge for China to raise the efficiency and drop the unit energy consumption during its way to realize sustainable development.

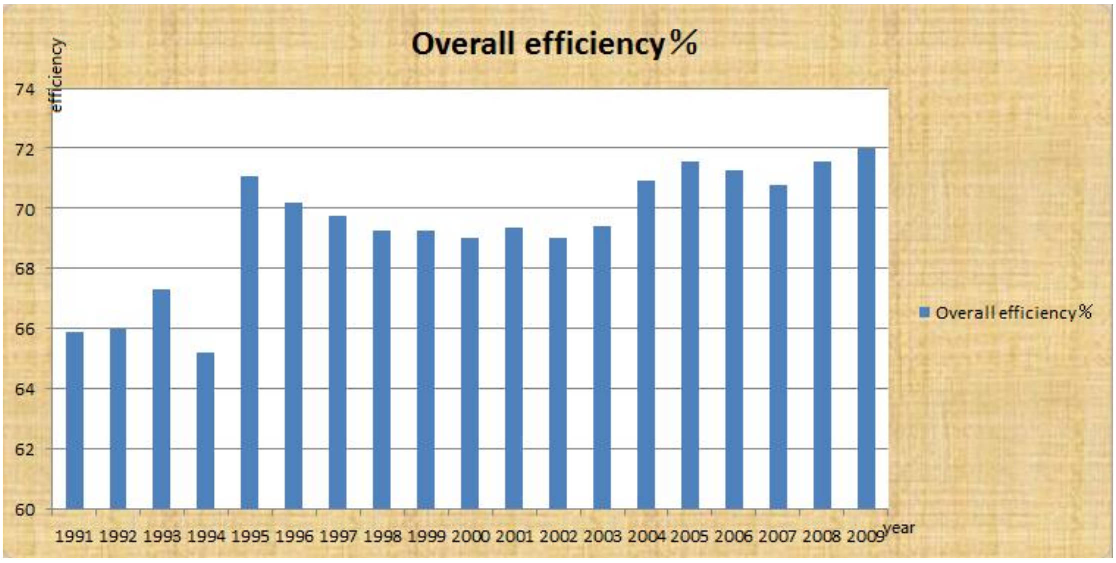

Figure 3: Overaa efficiency% (from table 4)

1.3 The energy consumption begins to become clean and environment-friendly

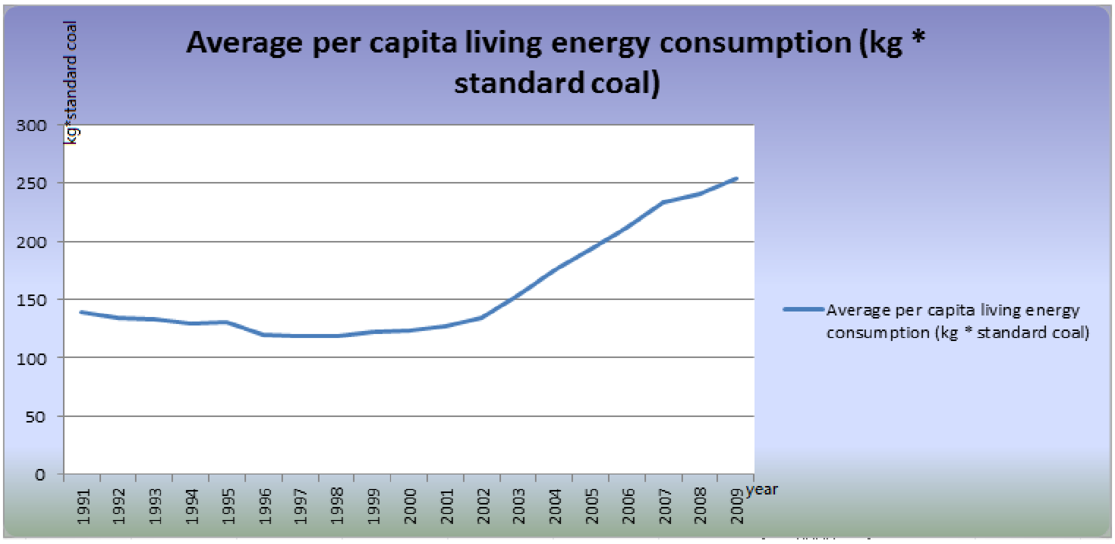

Figure 4: Average per capita living energy consumption (from table5)

Since the 1998, Chinese per capita living energy consumption has increased in fluctuation, which increased to 254.2 kg of standard coal in 2009 from 139 kg of standard coal 1991. To be specific in consumption structure, the consumption in natural gas and coal gas was in the fluctuating rising trend: the per capita consumption of them in 2009 was 8.3 and 3.9 times as much as in 1991, respectively; the per capita living consumption of liquid oil gas and power continually increased, with the 47.2 KWH of power in 1991 rising to 365.9 KWH in 2009, and 1.8 kg of liquid oil gas to 11.2 kg; in the meantime, the per capita consumption of coal dropped to 68.5 kg in 2009 from 143 kg in 1991(the specific data is shown in Table 5). These results indicated that Chinese residents' living energy consumption is gradually becoming clean and environment-friendly.

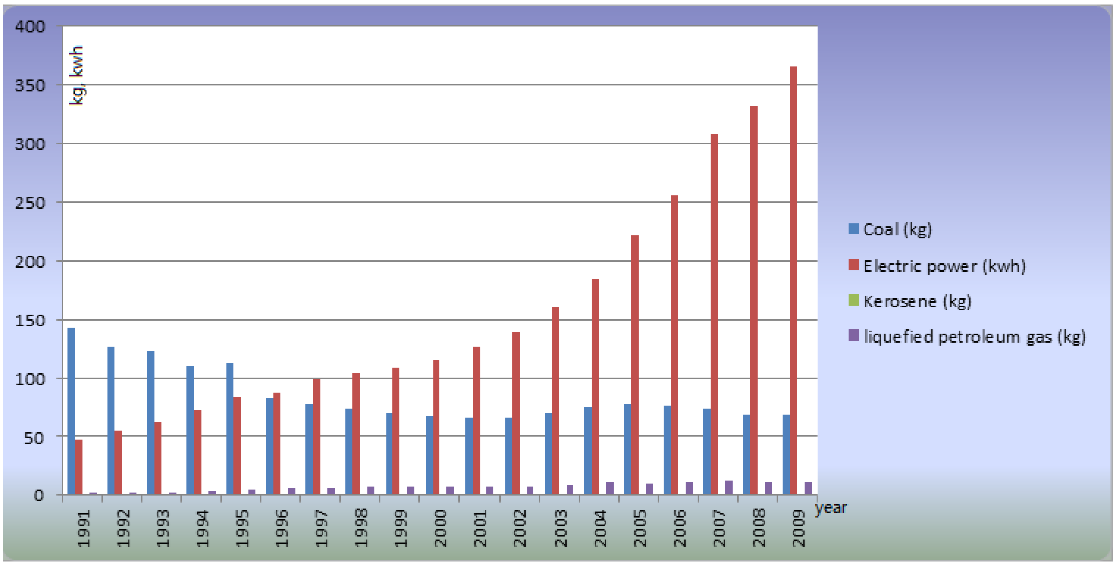

Figure 5: Living energy consumption (from table 5)

Furthermore, volume of the exhaust gas which is purified took 45.12% of the total in 1991, and the figure rose to 54.24% in 2000 (for detailed data, see Table 6). It can be seen that China is paying more and more attention to environment projection in the area of energy field. It will be a key and difficult point to reduce the environmental pollution caused by energy consumption and to develop clean new energies for China's future technological development.

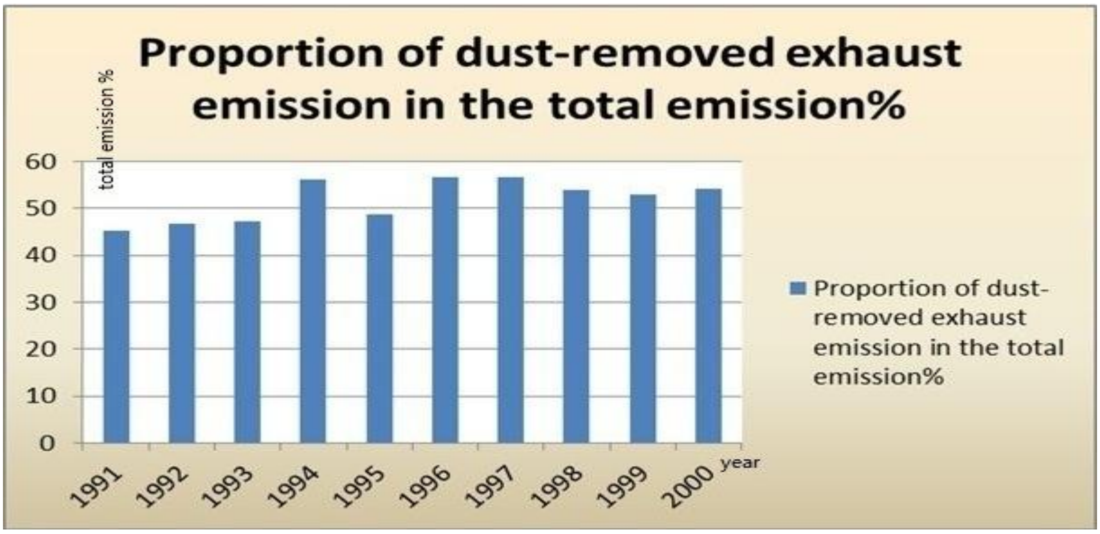

Figure 6: Proportion of dust-removed exhaust emission in the total emission% (from table6)

1.4 Newly added fixed assets of energy industry are large in amount every year, but the industrial distribution is not even

The increased amount of fixed assets in China's energy industry increased from 550.84 billion yuan of 2003 to 2162.71 billion yuan of 2010, taking 9%-14% of the total amount of all newly added fixed assets of all industries. Within the energy industry, the newly added fixed assets were principle in the power, steam, and hot water production supply industry, From 2003 to 2010, the proportion has been maintained at between 60% to 70%. During the period of 2003-2010, the output of Chinese power generation rose from 1910.575 billion KWH to 4141.26 billion KWH, with the growth rate being 117% which is far more than that (72.7%) of other energies that time. The second is the oil and gas exploiting industry, from 2003 to 2010, the proportion has remained between 14% -17%; the proportion of coal industry increased from 7.92% in 2003 to 17.50% in 2010. It is concluded from the above analysis that since the 1990's, key point in the development of China's energy industry lay in the power, steam, hot water production and supply industry as well as oil and natural gas industry, which implies that the technologies related to these industries have been the most basic and fundamental technologies in the recent development.

1.5 The energy industry is further modernized and the technology further improved

In the energy technology application field, the world has witnessed its big breakthrough since the 1990's. The power industry has generally mastered the design, construction, debugging and operating technology of the 600 thousand KWH sub-critical heat electric unit and 500 Kv AC/DC transmission/transformation power engineering; the hydroelectric power station construction has entered the world's advanced class, and the grid operation has primarily realized the automatic and modernized management; the complete equipment of 300MW water-pressure pile of the nuclear power station is able to be designed and produced on our own and the nuclear technology and resource are possessed; the comprehensive mechanical coal exploitation technology has reached in the world's advanced level, the annual output of over 5 million ton on a work surface has been achieved, and the capacity has obtained in designing, constructing, equipping and managing the ten-million-ton-scale open-air coal mine and large- and medium-sized mine area; the oil industry has form a complete system ranging from the scientific study, exploration & development, surface engineering construction to equipment manufacturing, of which the oil field early flooding stratified exploration, steady exploration of oil field contain much water, increasing the recovery ratio by polymer flooding, rolling exploration and development of complex fault-block oil field and other technologies have reached the world's advanced level; the application of wind power and solar power has gone into a new phase, in which the small-scaled wind power station is widely used in China's border areas where there are no big grids and the application scale of solar power is in the world's lead, while the property and quality of solar water heater have reached the international standard; the new-type power lithium-ion battery and fuel battery are also in the new progress of application study. All these have established a solid technological foundation for the further development of China's energy technology.

1.6 Different degrees of progress have been obtained in the management system of energy industry

The price of coal has primarily opened, and the production, transportation and marketing of coal have completely been open to the market. In some key-point state-owned coal mines, the reform has been thoroughly unfolded to establish a modern enterprise system; meanwhile, the bankruptcy work of some state-owned enterprises has been in implementation. In the oil and natural gas industry, the two giants of Sinopec and PetroChina have been restructured, realizing the integration of exploration & development, process & application and imports & exports. Besides, the raw oil and finished oil enter the international market due to the separation of the two large companies' central and non-central business as well as their success in listing on overseas. In the power industry, the government functions are separated from enterprise management, and the reform objective of "separating the plant from the grid, getting on the grid by bidding and supervised by the State" has been established. The marketization degree of the energy industry is further improved, thus creating the politic condition for the further development and application of the energy technology.

2. Development level of China's energy technology

No technology can be improved and developed without the existing technical level, with no exception to the energy technology. The development status of the energy technology is the foothold and springboard of the further development of China's energy technology. Currently, the overall technological level of China's energy industry is below the world's advanced level, with some specific technologies being on the world's advanced level. On the one hand, the energy technology has provided a fairly solid material and technological foundation for the further development of China's energy technology. On the other hand, it shows that China's energy technology has a vast development potential as we as faces big challenges. The principle level of China's present energy technology can be summarized in the following aspects:

2.1 Coal exploiting and processing application technology

Presently, China is able to independently design and manufacture the comprehensive mechanized coal mining complete equipment which can adapt to multiple coal bed geological conditions. The caving coal technology of heavy high seam integrated mechanization has rated on the world's leading level; besides, the working surface of more than 5 million ton of annual output as we as the ability to manage ten million ton scale opencast coal mine and large- and medium-sized coal area. The comprehensive utilization of coal ash has been on the same level with developed countries, but the use scope and ratio still need to be improved. About the clean coal technology, that of coal process, combustion, transformation and development has been made great progress since the 1990's; besides, the organizational administration institutions has been primarily formed and corresponding regulations have been gradually improved.

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However, we should see the gap between China and developed countries in the coal dressing technology: in China, the proportion of advanced coal dressing craft is low, scale of coal dressing plant small, automaticity low, equipment reliability weak and productivity low. Soft coal smokeless combustion technology and moulded coal processing equipment and stove transforming technology need to be further studied. The experience in design, construction and operation of large-scaled industrial coal dressing plant is not rich yet. The coal water slurry (CWS) on-site pulping technology, transporting and storage technology and the within-furnace contaminant release technology are far from sound. China’s new-type combustion technology including the fluid bed combustion technology, fuel coal combined cycle power generating technology and other high-efficiency and clean combustion technologies are still at the small-scale or experimental stage, far falling behind that of developed countries in both scale and technology. China’s coal transforming technology is still backward, giving priority to the small and medium-sized lump coal fixed bed gasification technology which highlights backward standard, low efficiency, serious pollution and other problems, and the coal direct liquefaction technology is still at the study stage. The desulfurization technology of limestone injection in the coal-fired boiler and desulfurization technology of smoke ejecting circulation fluid Bed are still under experiment, and the design and production of the coal-fired boiler desulfurization are still far more backward than those of developed countries.

2.2 The exploration, exploitation and processing utilization technology of oil and natural gas

Presently, China has obtained the world’s leading technology in complex fault block oil and gas exploration, oil field early flooding stratified exploitation, steady exploration of oil field contain much water, and rolling exploration and development of complex fault-block oil field. About the natural gas exploration, the earthquake collection, process, explanation (hilly area and high-definition earthquake) and other technologies in complex areas, the reservoir stratum prediction technology (sand body prediction and oolitic beach prediction), hydrocarbon (HC) test technology, unbalanced drilling supporting technology, special well logging (imaging well logging) technology, low porosity permeability gas reforming technology (large-scale fracture, $C0_2$ fracture) and other technologies are also increasingly perfected and improved, and the coal bed gas exploration engineering is almost mature. In China, the study on the oil chemical engineering catalyst as well as its industrial application has been in the lead of the world, plus the hydro-cracking technology which is increasingly mature, so that both the technique or catalyst are catching up international standard. China has developed the new-style drilling machine specially adopted in hilly areas and deserts; meanwhile, the technology is still backward in the intelligent control on the drill stem system, the removal and collection of drillings and the drilling fluid which helps stabilize the wall of the well while the drilling speed is quite high.

Coalbed methane drilling rig hydraulic system

2.3 Power construction and generator set technology

Three Gorges Dam

China's hydroelectric technology has been on the international level. China's is constructing The Three Gorges hydroelectric power station (18.2 million KW), which is the largest conventional hydroelectric power station in the world. By far, China's has built the largest-scale pumped-storage power station, i.e. Guangzhou Pump-storage Power Station (24 million KW). The completed 240M-high Ertan dome dam ranks the fourth in height among the world's high dome dams. The 178m concrete face rock-fill dam of Tiansheng Bridge level-one power station ranks the world's second. The technology of high-concentration coal ash, low-density and whole fracture surface thin layer rolling and continual placing concrete rolling ranks in the world's advanced class. China's has mastered considerably mature technologies in the design and construction of the earth and rock-fill dam, concrete gravity dam, arch dam and concrete face rock-fill dam. During the construction of hydroelectric power station, China has accumulated abundant experiences in the sediment control technology and essentially formed a set of hydroelectric power station operating method and sediment ejection scheme which are adaptive to feature of China's river load. However, during the construction, the roadheader has not been frequently used, and the degree of mechanized construction is low; besides, the study and utility of magnesium oxide micro-expansive concrete are still at the primary stage. China has generally mastered the design, construct, debugging and operating technology of the 600 thousand KW subcritical thermal power generating set and 500 KV DC/AC transmission and transformation project. China has been able to independently produce 400MW hydroelectric generating set, has produced the Ertan 550MW hydroelectric generating set in cooperation, and is producing the Three Gorges 700MW hydroelectric generating set in cooperation. Through the technology import, joint production and cooperative production, China's large-scale hydraulic generator set is now quickly approaching the world's advanced level. Meanwhile, a lot of problems further need to be solved in the model test of water turbine, function parameter, on-site process, welding, cavitation & abrasion, comprehensive optimization of water turbine and the stability of water turbine operation.

2.4 Nuclear power, solar power, wind power and other technologies

China's got the nuclear technology and nuclear fuel resource, and it is also able to independently design the 300MW complete pressurized-water-reactor (PWR) equipment for nuclear power station. By now, it has established the nuclear fuel cycle, from the uranium mine exploration, collection, transformation, uranium isotope separation, nuclear fuel component production to irradiated fuel processing, and mastered the ability to design, produce, construct and operate nuclear power. However, the domestic production of key equipment is low, with both per KW engineering cost and generating cost being twice of the internationally advanced level. Therefore, it will be a challenge for nuclear power development to improve the domestic production level and reduce the unit cost in the future.

Presently, the photovoltaic generation is the most precious recyclable energies in China. Its average price is 10 peak watt/100 dollars, lacing market competitiveness. The utility scale of solar water heater takes the lead in the world: the sales volume in 1999 was 5 million m^2 and the building area of passive solar houses in 1998 was 15 million $m^{2,}$ both of which ranked the world's first. The import substitute rate of wind power equipment is low, only 40%, and the industrial scale hasn't been formed. As of 1999, the aggregate installed capacity of the whole country's wind power plants was

268.3 thousand KW, with the average generation cost being 0.551 yuan/KWH.

Wind Power Station in Dongtai, Jiangsu

Therefore, the key point is to lower the wind power generation price and increase the import substitute rate of the wind generating set. Generally speaking, the development of commercialized renewable energy is still limited, so the key to develop recyclable energies lies in the market popularization and cost decrease.

3. The challenge to the development of China's energy technology

The strategic purpose of China to develop energy technology should be to solve the problem existing in the energy development and realize the sustainable development of the energy, while the source of power is exactly the challenge to China's energy development. Currently, the major challenges to China's energy development are the difficulties in realizing safe supply, high quality, high efficiency, optimal energy environment and structure, and all those will depend on the progress and development of technologies.

3.1 The challenge to ensuring the total quantity of the energy supply

In 2010, the total quantity of China's energy consumption reached 3.25 billion ton standard coal, taking 20.3% of the world's total amount, the first of the world. According to the requirement of building a well-off society in an all-round way, Chinese GDP in 2020 will quadruple that of 2002, i.e. 35.3 trillion yuan. Counted on the present worth of 2002, the energy consumption of per thousand yuan GDP is 0.137-ton standard coal. Taking all of the structure adjustment, technological progress and energy saving into account, the energy consumption of per thousand yuan GDP will increase by 3.5%-4% or so per year, so the figure in 2020 will be about 0.66-0.72 ton of standard coal, which means the total consumption of the whole country will be 2.32-2.54 billion ton of standard coal, about 9.3-115 ton more than that of 2002. In 2020, the total consumption of energy in China will be as high as 2.54 billion ton. Estimating in accordance with the relationship between the average energy output and the fixed asset growth of energy industry in the period of 1991-2001, even if 60% of the 2.5 billion ton of coal will be produced in China, the energy industry will need to add new fixed assets numbered 6622.9 billion yuan, 367.9 billion yuan per year on average; if 85% will be produced in China, the newly added fixed assets of energy industry will be 9382.4 billion yuan, about 521.2 billion yuan per year. Therefore, even if all the investment will be converted into the fixed asset, the pressure on the investment in the energy industry will still be considerably heavy.

In 1998, the per capita commercial energy consumption was 0.83-ton oil equivalent, while that of high-income countries was 5.36 ton in average, Europe Union countries 3.84 ton in average, Japan 4.035 ton and the USA 7.94 ton. In 2050, China is expected to be a moderately developed country, where if the per capita energy consumption is assumed to be 3.5 ton and population 1.5 billion, the total energy consumption of China in 2050 will be 5.25 billion ton oil equivalent, equal to 60% of present word's total consumption. Based on the above analysis, we know that the national economy growth and rise of people's living stand will be confined by the resource and capital supply if they are expected to be achieved depending on the existing technology plus the increase of energy supply. In that case, the energy supply of both China and the whole world will be facing a great challenge which can be only handled with the improvement and development of the energy technology.

3.2 Energy supply is confronted with challenges in the aspect of diversification and quality

Nowadays, coal takes a considerable proportion in the diversified supply structure of primary energy in China. Taking the statistical result of 2010 as the example, in the 2.97 billion ton of standard coal produced in China, the coal took the proportion of 76.5%, oil 9.8%, natural gas 4.3% and hydro power 9.4%.

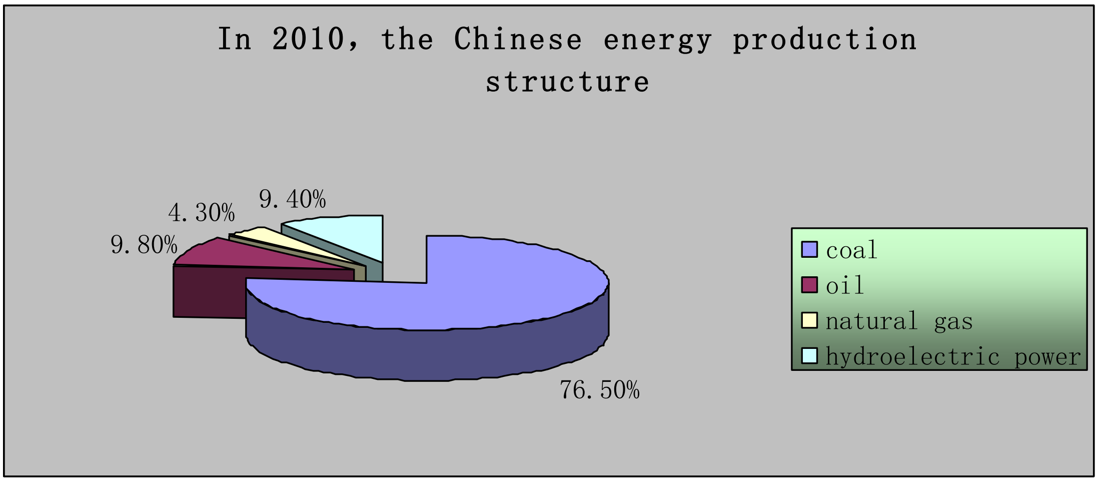

Figure 7: Chinese energy production structure in 2010

This present energy supply structure of China is related to both China's energy resource condition (in the proven mineral energy resource, the coal takes 96%, while the oil and gas combined only 4%) and China's past development model, i.e. "focusing on the capacity growth and ignoring the structure optimization", of energy industry. Since the 1990's, thought the proportion of coal has descended, this coal-oriented energy structure will hardly be changed in the near future; besides, the main usage of coal will still be power generation and others, such as the thermal power generation where the installed capacity takes 74.39% of the whole country's power installed capacity. To optimize China's energy structure, the coal usage must be perfected in the near future, which means the clean coal technology will be developed to handle the pollution caused by the coal combustion; secondly, new methods of converting coal energy in the future, such as developing the gasification and liquefaction technology and poly-generation technology, improving the energy system efficiency of the gasification and liquefaction.

To optimize the energy structure, the proportion of hydro power should be raised in the energy supply. China is rich in waterpower resources. However, the present utilization rate is pretty low, only 27%, and the hydroelectric power installed capacity only takes 24.5% in the total power installed capacity. Compared with the various environmental problems generated in the production, transportation and power generation, the influence of hydro power on the environment and ecology is much lower. However, in China, the waterpower resource is distributed unevenly, of which 70% is concentrated in the southwestern areas far from the load center. Therefore, China's hydro power development is confronted by serious problems in the economic long-distance power transmission, the ecology influenced by hydro power development and the engineering technology of hydro power development in special geological condition.

One of China's objectives to optimize the energy structure is to raise the proportion of the natural gas in the energy structure. In the world's primary energy structure, the natural gas takes 23.2%, while in China, 4.4%. It is estimated that the reserve of the natural gas in China is about 10 trillion cubic meters. As of 2000, the proven reserve was 2.3 trillion cubic meters, of which the economic yield was 1 trillion cubic meters. According to China's present productivity of natural gas, the gross of the natural gas isn't a constraint. However, the reserves of natural gas are distributed unevenly. Therefore, the long-distance tube transportation, storage, capital and cost of natural gas exploitation are the greatest challenges to us.

The nuclear power is a reliable and clean energy, and its reliability has been pretty high now. With the present technology, the nuclear waste can be disposed appropriately. To development nuclear power conforms to China's strategic orientation of realizing the sustainable energy development. However, the installed capacity of nuclear power in China is only 1.4% of the total power installed capacity. All of the nuclear resource, scale and cost are the key factors that influence China's nuclear power development.

As the wind power and solar power generation is just started in China, the key point in the past was focused on the energy supply in rural and remote places. In recent years, the modern commercialized recyclable resource has gradually become the developing key point, of which the solar water heater has form a scaled market and the large-scale wind power generation is also trialed in many locations. However, the import substitute rate of the wind power equipment is 70%, but no industrial scale has been formed. All in all, the development of commercialized renewable energy resources is still pretty limited, so the key points to the renewable energy development are the market popularization and cost reduction.

3.3 Main challenges to the assurance of energy safety

With the year by year increase of China's imports of oil, natural gas and other good energies—the net import of oil in 2009 was 217.258 million ton, taking 56.6% of China's oil consumption—China's dependence on the international energy resource is increasingly rising, so the international emergencies and intense fluctuation of international oil market impose a great influence on China's oil supply safety. The safety problem in the gas and oil supply is the major in China's energy safety. Even after the energy structure optimizing measure is executed and oil substitute and energy-saving technology developed, which to some degree mediates the oil supply-demand conflict, it is still unavoidable that the shortage of domestic oil supply will be filled by imported oil. Though the dependence on Middle East can be reduced by optimizing the import strategy, the source of oil import will still be Middle East in the future. Therefore, it's necessary to establish the national strategic oil & gas reserve for ensuring the supply safety of oil and gas as well as maintain the overall interest of the country. However, all of the oil & gas reserve safety technology, construction capital, natural gas pipeline transportation and the technology of handling emergent safety accidents happening in reserves are confronted by severe challenges, and they are also the weak links in China's present technological power.

3.4 Main challenges to the area of energy environment

To protect the environment is a main point of energy sustainable development, but it was not emphasized in China's past energy development. In 1997, the $C0_2$ discharge in China was 3593.5 million ton, 15.05%[1] of that of the whole world, of which 3449.5 million ton was generated by the energy activity. In 2010, the discharge of SO_2 and dust was 21.851 million ton and 8.291 million ton, of which 70% of the SO_2 and 70% of the dust were generated by the combustion of coal[2]. Presently, only 55% of the total exhaust emission in China has been dust-removed, and half of China's northern cities and 1/3 of southern cities are under the threat of exceeded SO_2, leading 30% of the whole country suffers from the harm of acid rain. Under the condition that the coal-oriented energy structure of China can be changes in the near future, the most severe challenge to then energy development and transformation includes developing and popularizing the environment friendly equipment for coal combustion and controlling the exhaust emission of the energy combustion.

[1] Development Index, World Bank, 2001

[2] Situational Analysis of China's Sustainable Development Energy and Carbon Emission, Energy Bureau of National Development and Reform Commission, 2003

In addition, the great challenges and problems to the energy environment also includes the earthquake, rise of ground water and silt deposit induced by large-scale hydroelectric projects, the ground sink and underground water destruction caused by coal exploitation, and the influence of the deserted mineral well on the environment. Of course, the energy environment problem is related to the optimization of the energy structure, so it is a long-term challenge to develop new-style clean alternate energy sources.

4. The system innovation of the energy technology development

The rational system and mechanism are the power source to maintain the sustainable development of the energy technology. Currently, China's has made primary exploration and innovation in the source of the R&D capital, culture and education of talents, management of the R&D subject, motivation security and supervisory mechanism, and decision making and identification system of the research result, etc., in hope of gradually solving the existing problems and thus ensuring the further development of the system and mechanism.

4.1 Investment to energy technology

The technological investment consists of the talent investment and capital investment. As to the personnel investment, the technological development staffs in the large-scale enterprise of coal mining and processing industry has increased by 120% since 1995 and numbered 55668 in 2001, of which the staffs of technological development institutions have increased by 239%, and the R&D staffs are beginning to concentrate in technological development institutions. In the oil and gas mining industry, the total personnel decreased to 47142 in 2001 from 70348 in 1995 due to the institutional reform, but the scientists and engineers up to R&D increased from 26970 in 1995 to 34637 in 2001, which means the proportion of the R&D staff is rising. During the period of 1995 to 2001, the number of technological staffs in the oil processing and coking industry didn't change much, increasing from 23614 to 22482, but that of scientists and engineers up to R&D increased from 8662 to 14165, an increase of 63.5%. Between 1995 and 2001, the technological staff in the power, steam and hot water production and supply industry increased from 23732 to 54285, with the growth of 130%, and the scientists and engineers up to R&D increased from 10096 to 35456, an increase of 251%, far faster than that of technological staffs. The technological staffs of coal gas production and supply industry increased from 1248 in 1995 to 2048 in 2001, and the scientists and engineers from 592 to 1386, with growth being 134%, but the R&D staffs are still too few. As far as the whole energy industry is concerned, the proportion of technological staffs to the total of the country rose from 11.68% in 1995 to 13.28% in 2001 (for more details, see Table 8), indicating that the talent investment of energy industry increases faster that the average of all industries.

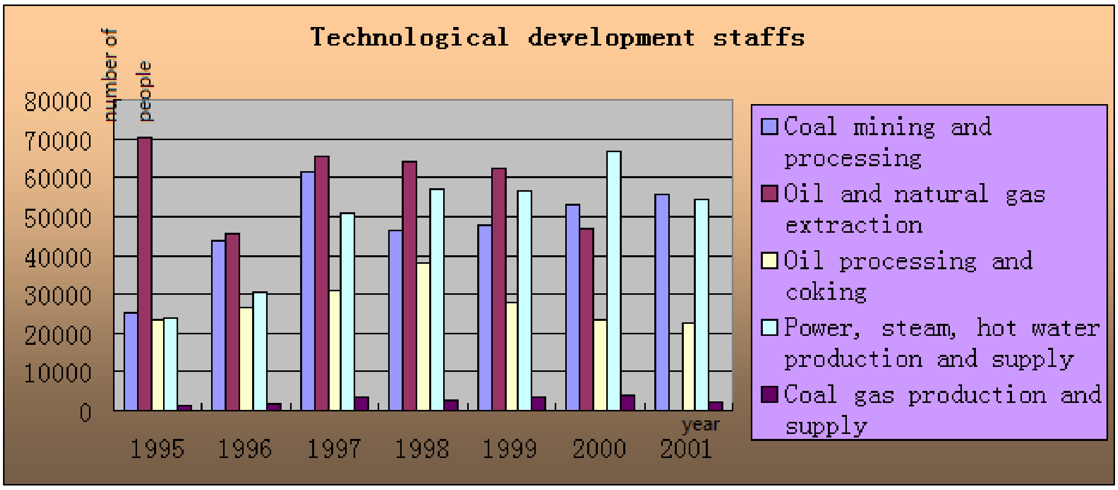

Figure 8: Technological development staffs (from table 8)

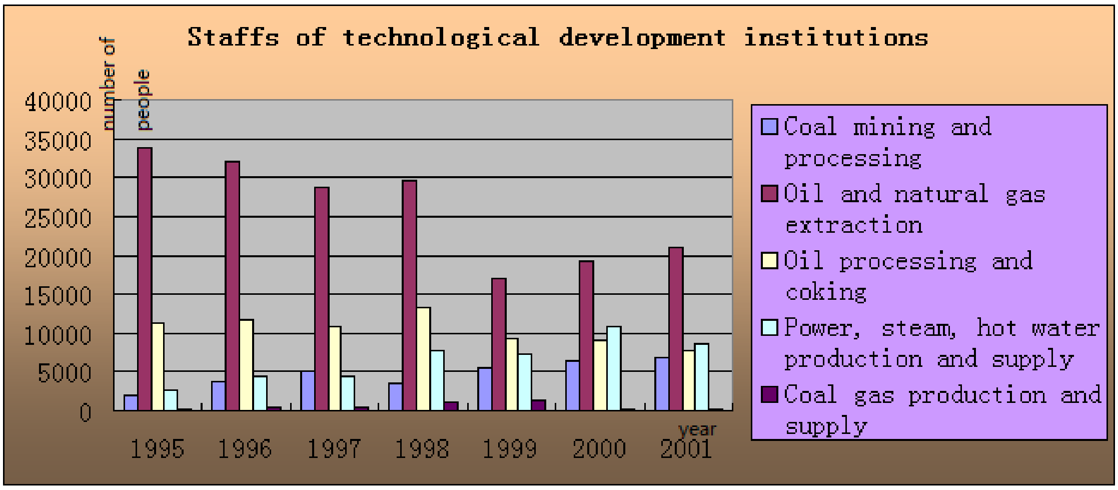

Figure 9: Staffs of technological development institutions (from table 8)

About the capital investment, the energy industry has essentially formed a scientific research system with diversified, enterprise-oriented capital investment. In large- and medium-sized enterprises, the enterprises' own research funds take the proportion of more than 70% in the entire research fund, and in 2001, the ratio was as high as 88.83%; on the contrary, the proportion of governmental funds was on a declining curve, reducing to 1.17% in 2001[1]. The total capital investment of the five sectors of

[1] Governmental capitals are principally invested in the National hi-tech research development plan (863 Plan), national scientific and technological program for tackling key problems (the Program for Tackling Key Problems),

the energy industry was in an increasing tendency year by year, which, between 1995 and 2001, for example, increased from 4576207 to 10150070 thousand yuan, with the total growth being 120% and annual growth being 20%; among these capitals, those raised by enterprises increased from 3339113 thousand yuan to 9016760 thousand yuan, with the aggregate growth being 170% and annually average growth 28.3%; in the period of 1995-2001, the research fund of the five sectors of energy industry took around 10% of the funds of all industries of the whole country, but proportion of the governmental research fund in that of the large- and medium-sized enterprises of the energy industry decreased from 23.22% in 1995 to 2.89% in 2001 (for more details, see Table 9), so the investment system of energy research is gradually transformed into the enterprise-oriented.

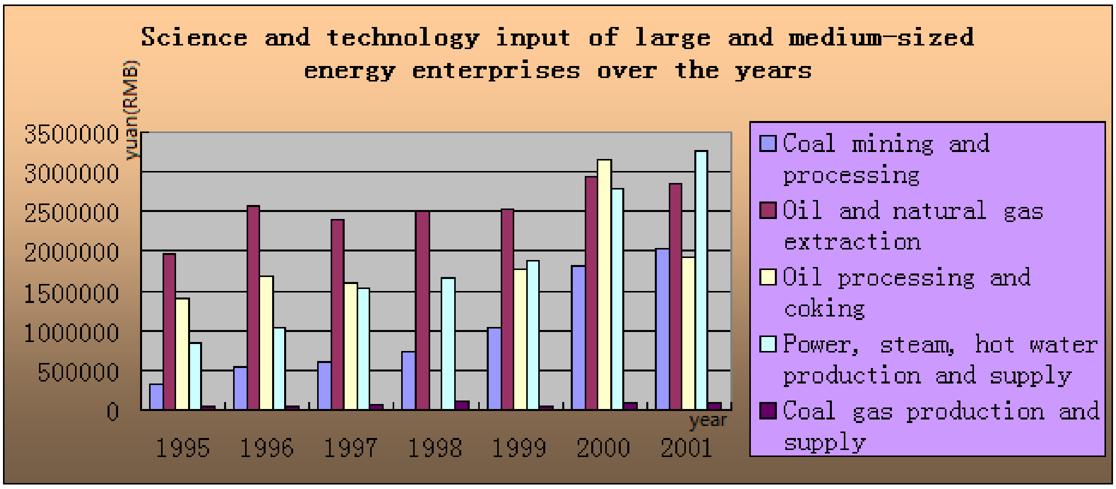

Figure 10: Science and technology input of large and medium-sized energy enterprises over the years (from table 9)

Even so, the scientific research development and technological innovation ability in the energy industry is still unable to meet the need in production and development. Taking the petrifaction as an example, the scientific and technological level of China’s oil and chemistry is far lower than international level. Lacking autonomously developed central technologies, most of the product production and equipment technologies are more backward that developed countries’; furthermore, the R&D investment of China’s oil and chemical industry is only 0.5%-1% or so, far lower than the 3%-10% of developed countries. Lack of technological investment, especially talent and capital investment, is the key point that constrains China’s development in energy technology.

national key-point basic research development plan (973 Plan) and other national large-scale scientific research projects, in hope of promoting the boost of key or fundamental technologies and theories.

4.2 R&D subjects of energy technology

Currently, the innovation institutes of China's energy industry area have almost formed a scientific research institution system in which the corporate research institutions are the lead while the national scientific research institutions and higher education institutions are also involved. The research field of corporate research institutions generally covers the basic theory, applied technology, hi-tech technological research and other areas of the industry, and professional and fairly complete research institutions have been formed. However, the mutual cooperation and connection between these institutions is relatively poor, and the overall research strength of each institution is weak. Besides, there are too few research fields in China that are at the internationally advanced level. Presently, though some reconstructions and reforms are implemented in China's energy research structure, the overall situation of sparse structure, small scale and weak cooperation hasn't been changed. In Table 10 list some major research enterprise institutions of the energy industry along with their research areas, by which we can form a simple understanding on the research institution of energy industry.

Among all the research subjects, the innovative talents are the core of innovation. Nowadays, the innovative talent cultivation of energy industry can be classified as four models: (1) culturing excellent talents in practice; (2) establishing the research group with international standards by enhancing the international academic exchanges; (3) giving full play to the advantage of the research institution, thus culturing high-class talents. The composition of the research personnel of energy industry is generally the model of "on-post staffs plus temporary employees", and the title and degree of the researcher are both high. Taking the electric power research institute as an example, the ratio of on-post staffs to temporary employees is 750:550, and among the on-post staffs, 35.8% hold advanced or higher titles, 41.2% hold the diploma of master or higher and 16.8% have the special government allowance. Currently, China's energy technological innovative talent resource is generally composed of academicians, senior experts and professors enjoying the special government allowance, young experts having special contributions to the nation and young doctors and masters, which is in an echelon structure and talent innovation model which is in line with China's energy technology area and market economy. However, the research talents are still insufficient, especially the key technology research staffs and internationally famous experts, and this situation is the most severe problem to the talent innovation resource of China's energy technology R&D.

4.3 Politic supporting system of energy technology

4.3.1 Supportive policies of capital investment

Currently, the energy research institution is being turned into the enterprise so as to face the market directly. This action promotes the reconstruction and integration of all institutions and optimizes the technological power and resource allocation, thereby further performing the comprehensive advantage and boosting the technological innovation and its industrialized development. In recent years, the nation has paid more and more attention to the energy technology, and the enterprise has also invested more and more into R&D, but the investment lacks an effective diversified innovative activity financing system and the corporate investment is still not enough. Maybe this situation is caused by many factors, but one of the important is that the nation hasn't set out corresponding incentive policies (such as tax preferential policy and loan discount policy) supporting corporate RAD.

4.3.2 Evaluation system of research results

Presently, China's research result identification and reward system is pretty imperfect, and the corruption phenomenon is shocking, with no exception to the energy industry. These defects principally lie in the boast of research results, self-selecting juries and rash overview process, etc. During China's technology appraisal work, the organizational identification department is only the formal subject of appraisal work, which is the essential cause various defects in the appraisal work. Generally speaking, the process of transforming the technological result into productivity must experience four stages: basic research, applied research, engineering research and commercial research, but there are not corresponding requirements made on the four stages, making the jury feel hard to make exact decisions and allowing the opportunist to exploit an advantage. Besides, the expert overview system lacks standardization; experts don't seriously follow the avoidance; the punishment system isn't sound; the legal liability is not explicit, leading to the embarrassing situation that some illegal behaviors are not mentioned by the rules. All the conditions objectively requires us establishing a set of independent, public and impartial and scientific evaluation system, thus ensuring the healthy development of the energy technology.

4.3.3 The incentive and supervising system for researchers

With the primary establishment of the market economic system of energy industry in China, the research institutions of this industry are almost transformed into enterprises; besides, the market-economic-based distribution system, incentive system, competitive system and innovative activity scientific evaluation supervising system are being formed. However, due to the overall process of the reform of China, the employee social security mechanism and talent flow mechanism in the energy science and technology institutions are the fundamentally major factors that constrain the function of the market in talent resource allocation. Though some research institutions implement the system of employment under contract for research specialist staffs, the traditional management model of research talent title evaluation system is universally existing, which impedes young talents' growth and technicians' initiative. As far as the bonus is concerned, the researcher's income and research result are not sufficiently connected, lacking incentive mechanisms; besides, the risk management mechanism of the scientific and technological institutions is backward, risk and income being not really connected. About the selection of the research subject, the bidding mechanism of Chinese scientific research item is just begun, so it lacks rigorous executing and supervising regulations.

4.3.4 Policy environment of technological development

With the deepening of the reform of scientific and technological system, the continual implementation of national technological innovation project and knowledge innovation project, and the construction of scientific and technological medium service system, scientific research system and infrastructure, China has primarily established a national innovation system which is conforming to the need of socialist market economy and the development discipline of the technology. The policy environment of the scientific research development is being optimized, fiscal and financial policies in favor of technological development made and implemented, and the intellectual property projection policy further improved. In particular, the implementation of "developing the country through science and education" strategy and the establishment of the "Tenth-five Planning" of technological development are leading the way for the technological development of energy industry. In the meantime, the national "Eleventh-fifth" technological planning and "Program for National Scientific and Technological Development (2006-2020)" are being made, which are in favor of creating a good environment for China's energy technology development.

5. Conclusions

With the ceaseless deepening of the reform and opening up policy in energy area and the continual implementation of going-out strategy, the energy industry will more rely on the technological improvement to realize development and improve international competitiveness. However, the China’s foundation in this area is fairly weak, and some advanced technologies and universally backward technologies coexist. In the oil, coal and power field, a corporate scientific research system has been primary established, but the critical technological research is still invested by the state. The investment channel of the scientific research fund is relatively single, and that of the new energy development and application research is insufficient, especially that of significantly strategic technological study. Though the reformation of personnel management has made a big progress, inside the R&D system, it still lacks an effective incentive and supervising mechanism. The immature technological personnel market constrains the appropriate mobility and competition of skilled personnel. Besides, the lagged promotion and application of scientific and technological achievements, weak capacity in market exploration and low industrialization are all the problems that need to be solved. Though the scientific and technological exchange with other countries is more and more frequent, the overall R&D capacity is still much weaker than that of developed countries. Presently, China’s energy technology is facing various challenges from the systematic innovation, technological innovation and management innovation.

Attached tables

Table 1 Statistical chart of China' energy production and consumption structure since the 1990's

year	Energy production (ten thousand ton of standard coal)	Proportion in the total energy production (%)				Total energy consumption (ten thousand ton of standard coal)	Proportion in the total energy consumption(%)				Total production-consumption difference(ten thousand ton of standard coal)
		Raw coal	Raw oil	Natural gas	Hydro power		coal	oil	Natural gas	Hydro power	
1991	104844	74.1	19.2	2	4.7	103783	76.1	17.1	2	4.8	1061
1992	107256	74.3	18.9	2	4.8	109170	75.7	17.5	1.9	4.9	-1914
1993	111059	74	18.7	2	5.3	115993	74.7	18.2	1.9	5.2	-4934
1994	118729	74.6	17.6	1.9	5.9	122737	75	17.4	1.9	5.7	-4008
1995	129034	75.3	16.6	1.9	6.2	131176	74.6	17.5	1.8	6.1	-2142
1996	133032	75	16.9	2	6.1	135192	73.5	18.7	1.8	6.0	-2160
1997	133460	74.3	17.2	2.1	6.5	135909	71.4	20.4	1.8	6.4	-2449
1998	129834	73.3	17.7	2.2	6.8	136184	70.9	20.8	1.8	6.5	-6350
1999	131935	73.9	17.3	2.5	6.3	140569	70.6	21.5	2.0	5.9	-8634
2000	135048	73.2	17.2	2.7	6.9	145531	69.2	22.2	2.2	6.4	-10483

2001	143875	73.0	16.3	2.8	7.9	150406	68.3	21.8	2.4	7.5	-6531
2002	150656	73.5	15.8	2.9	7.8	159431	68.0	22.3	2.4	7.3	-8775
2003	171906	76.2	14.1	2.7	7.0	183792	69.8	21.2	2.5	6.5	-11886
2004	196648	77.1	12.8	2.8	7.3	213456	69.5	21.3	2.5	6.7	-16808
2005	216219	77.6	12.0	3.0	7.4	235997	70.8	19.8	2.6	6.8	-19778
2006	232167	77.8	11.3	3.4	7.5	258676	71.1	19.3	2.9	6.7	-26509
2007	247279	77.7	10.8	3.7	7.8	280508	71.1	18.8	3.3	6.8	-33229
2008	260552	76.8	10.5	4.1	8.6	291448	70.3	18.3	3.7	7.7	-30869
2009	274619	77.3	9.9	4.1	8.7	306647	70.4	17.9	3.9	7.8	-32028
2010	296916	76.5	9.8	4.3	9.4	324939	68.0	19.0	4.4	8.6	-28023

Data source: China Statistical Yearbook (2011)

Table 2 Statistical table of China's energy and power production and consumption coefficient of elasticity

year	Growth speed of GDP	Growth speed of energy production	Growth speed of power production	Growth speed of energy consumption	Growth speed of power consumption	Coefficient of elasticity of energy production	Coefficient of elasticity of power production	Coefficient of elasticity of energy consumption	Coefficient of elasticity of energy consumption
2010	10.4	8.1	13.3	6.0	13.2	0.78	1.28	0.58	1.27
2009	9.2	5.4	7.1	5.2	7.2	0.59	0.77	0.57	0.78
2008	9.6	5.4	5.6	3.9	5.6	0.56	0.58	0.41	0.58
2007	14.2	6.5	14.5	8.4	14.4	0.46	1.02	0.59	1.01
2006	12.7	7.4	14.6	9.6	14.6	0.58	1.15	0.76	1.15
2005	11.3	10.0	13.5	10.6	13.5	0.88	1.19	0.93	1.19

2004	10.1	14.4	15.3	16.1	15.4	1.43	1.51	1.60	1.52
2003	10.0	14.1	15.5	15.3	15.6	1.41	1.55	1.53	1.56
2002	9.1	4.7	11.7	6.0	11.8	0.52	1.29	0.66	1.30
2001	8.3	6.5	9.2	3.3	9.3	0.79	1.11	0.40	1.12
2000	8.4	2.4	9.4	3.5	9.5	0.28	1.12	0.42	1.13
1999	7.6	1.6	6.3	3.2	6.1	0.21	0.83	0.42	0.80
1998	7.8	—2.7	2.7	0.2	2.8		0.35	0.03	0.36
1997	9.3	0.3	5.1	0.5	4.8	0.03	0.55	0.06	0.52
1996	10.0	3.1	7.2	3.1	7.4	0.31	0.72	0.31	0.74
1995	10.9	8.7	8.6	6.9	8.2	0.80	0.79	0.63	0.75
1994	13.1	6.9	10.7	5.8	9.9	0.55	0.85	0.44	0.76
1993	14.0	3.6	15.3	6.3	11	0.27	1.13	0.45	0.79
1992	14.2	2.3	11.3	5.2	11.5	0.16	0.8	0.37	0.81
1991	9.2	0.9	9.1	5.1	9.2	0.1	0.99	0.55	1.0

Data source: Data source: China Statistical Yearbook (2011).

Table 3 average energy consumption per ten thousand yuan GDP

year	Total energy consumption (ton standard coal/ten thousand yuan)	Coal consumption (ton/ten thousand yuan)	Coke consumption (ton/ten thousand yuan)	Oil consumption (ton/then thousand yuan)	Raw oil consumption (ton/then thousand yuan)	Fuel oil consumption (ton/then thousand yuan)	Power consumption (ten thousand KWH/ten thousand yuan)
2002	2.63	2.42	0.22	0.44	0.4	0.07	0.29
2001	2.59	2.42	0.2l	0.44	0.41	0.07	0.28
200	2.68	2.56	0.21	0.46	0.44	0.08	0.28

0							
1999	2.89	2.8l	0.23	0.47	0.42	0.09	0.27
1998	3.15	3.08	0.26	0.47	0.4l	0.09	0.28
1997	3.53	3.57	0.28	0.5	0。45	0.1	0.29
1996	3.88	4.04	0.3	0.49	0.44	0.1	0.3
1995	4.01	4.21	0.33	0.49	0.46	0.11	0.31
1994	4.18	4.38	0.31	0.51	0.48	0.12	0.32
1993	4.42	4.61	0.34	0.56	0.53	0.14	0.32
1992	4.72	4.94	0.34	0.58	0.57	0.15	0.33
1991	5.12	5.46	0。35	0.61	0.61	0.17	0.34

Data source: Macroeconomic Database

Table 4 energy transformation efficiency of China

year	Overall efficiency％	Power generation and heat supply of power station％	coking％	Oil refining％
1991	65.90	37.60	89.90	98.10
1992	66.00	37.80	92.70	96.80
1993	67.32	39.90	98.05	98.49
1994	65.20	39.35	89.62	97.48
1995	71.05	37.31	91.99	97.67
1996	70.19	36.63	94.07	97.46
1997	69.76	35.89	94.01	97.37
1998	69.28	37.09	94.97	96.41
1999	69.25	37.04	96.13	97.51
2000	69.04	37.36	96.21	97.32
2001	69.34	37.63	96.48	97.92
2002	69.04	38.73	96.63	96.71

2003	69.40	38.83	96.13	96.80
2004	70.91	39.46	97.55	96.43
2005	71.55	39.87	97.57	96.86
2006	71.24	39.87	97.77	96.86
2007	70.77	40.24	97.56	97.17
2008	71.55	41.04	97.75	97.17
2009	72.01	41.73	97.38	96.63

Data source: China Statistical Yearbook (2011)

Table 5 Chinese per capita living energy consumption

year	Average per capita living energy consumption (kg * standard coal)	Coal (kg)	Power (kg)	Kerosene (kg)	liquefied petroleum gas (kg)	Natural gas (cubic meter)	Coal gas (cubic meter)
1991	139.0	143.0	47.2	0.8	1.8	1.6	3.2
1992	134.2	126.9	54.9	0.7	2.1	1.8	4.4
1993	133.5	123.2	62.5	0.6	2.5	1.5	4.6
1994	129.3	109.5	72.7	0.6	3.2	1.7	6.3
1995	130.7	112.3	83.5	0.5	4.4	1.6	4.7
1996	120.5	83.0	87.7	0.5	5.9	1.7	6.4
1997	119.3	77.2	98.6	0.5	6.2	1.7	8.9
1998	119.0	73.1	104.2	0.6	6.9	1.9	9.7
1999	121.8	69.9	108.6	0.6	6.8	2.1	9.3
2000	123.7	67.0	115.0	0.6	6.8	2.6	10.0
2001	127.2	66.1	126.5	0.6	6.7	3.3	9.4
2002	134.0	65.7	138.3	0.3	7.6	3.6	9.8
2003	153.4	69.9	159.7	0.3	8.6	4.0	10.2
2004	175.7	75.4	184.0	0.2	10.4	5.2	10.7
2005	194.1	77.0	221.3	0.2	10.2	6.1	11.1
2006	211.8	76.6	255.6	0.2	11.1	7.8	12.7
2007	233.8	74.1	308.3	0.1	12.4	10.9	14.1

2008	240.8	69.1	331.9	0.1	11.0	12.8	13.9
2009	254.2	68.5	365.9	0.1	11.2	13.3	12.5

Data source: China Statistical Yearbook (2011)

Table 6 China's exhaust emissions and dust removal ratio

year	Total exhaust emission	Exhaust emission during fuel combustion	Exhaust emission after dust removal	Proportion of exhaust emission during combustion in the total emission%	Proportion of dust-removed exhaust emission in the total emission%
2002	175257	103776		59.21	
2001	160863	93526		58.14	
2000	138145	81970	74928	59.34	54.24
1999	126807	75919	67026	59.87	52.86
1998	121203	72985	65231	60.22	53.82
1997	113375	70918	64135	62.55	56.57
1996	111196	70019	63012	62.97	56.67
1995	123407	66949	60032	54.25	48.65
1994	97463	61800	54782	63.4l	56.21
1993	109604	60041	51782	54.78	47.24
1992	104787	57221	48926	54.61	46.69
1991	101415	53649	45761	52.9	45.12

Data source: Macroeconomic Database

Table 7 newly added fixed assets in the energy industry capital construction

Unit: 100 million yuan, %

year	Newly added of all industries in China	Energy industry		Coal mining and processing		Oil and natural gas industry		Power, steam, hot water production and supply		Oil processing and coking		Coal gas production and supply	
		Added amount	Proportion in all industries	Added amount	Proportion in energy industry	Added amount	Proportion in energy industry	Added amount	Proportion in energy industry	Added amount	Proportion in energy industry	Added amount	Proportion in energy industry
2002	11989.69	3249.86	27.11	72.43	3.44	386.42	16.04	1662.2	75.65	86.阳	2.77	41。57	2.1
2001	10112.67	2021.43	19.99	59.84	2.96	420.1	20.78	1489.9	73.7l	25.42	1.26	26.1:	1.29
2000	10431.66	2478.86	23.76	134.47	5.42	336.92	13.59	1945.5l	78.48	31.09	1.25	30.8:	1.25
1999	9519.3	2171.38	22.81	176.77	8.14	224.83	10.35	1604.39	73.89	133.66	6.16	31.73	1.46
1998	8499.82	2127.39	25.03	83.59	3.93	202.41	9.51	1637.33	76.96	147.67	6.94	56.39	2.65
1997	7443.15	1683.7	22.62	190.37	11.31	261.15	15.51	1068.93	63.49	143.57	8.53	19.68	1.17
1996	6129.65	1297.17	21.16	99.61	7.68	135.33	10.43	922.64	71.13	108.09	8.33	31.5	2.43
1995	4712.67	1075.02	22；81	107.16	9.97	134.91	12.55	736.39	68.50	78.56	7.31	18	1.67
1994	3729.78	845.3	22.66	59.58.	7.05	104.09	12.31	605.42	71.62	59.61	7.05	16.6	1.96
1993	2758.93	622.45	22.56	76.27	12.25	91.21	14.65	383.32	61.58	37.12	5.96	34.53	5.55
1992	1975	578.86	29.31	82.77	14.30	85.06	14.69	354.13	61.18				
1991	1498.73	475.62	31.73	80.64	16.95	59.49	12.51	292.87	61.58				

Data sources: Macroeconomic Database, China Statistical Yearbook (2004)

Table 8 changes in technician investment of energy department

	1995		1996		1997		1998		1999		2000		2001	
	Technological development staffs	Staffs of technological development institutions	Technological development staffs	Staffs of technological development institutions	Technological development staffs	Staffs of technological development institutions	Technological development staffs	Staffs of technological development institutions	Technological development staffs	Staffs of technological development institutions	Technological development staffs	Staffs of technological development institutions	Technological development staffs	Staffs of technological development institutions
Coal mining and processing	25213	2048	43823	3802	61333	5027	46507	3435	47734	5531	53240	6354	55668	6948
Oil and natural gas extraction	70348	33806	45512	31943	65369	28656	64068	29597	62375	17087	46674	19231	47'42	21021
Oil processing and coking	23614	11312	26597	11690	31119	10831	38117	13216	27769	9374	23299	8994	22482	7720
Power, steam, hot water production and supply	23723	2672	30329	4401	51001	4502	57073	7634	56463	7335	66912	10830	54285	8708
Coal gas production and supply	1248	260	1706	387	3695	517	2664	1058	3711	1267	4052	236	2048	132
Amount of above five industries	144146	50098	147967	52223	212517	49533	208429	54940	198052	40594	194177	45645	181625	44529

Amount of all industries of the whole country	1234144	408880	1135680	384537	1474245	378208	1410365	410988	1463685	420548	1386556	440189	1367817	474533
Proportion of energy industry in all industries ％	11.68	12.25	13.03	13.58	14.42	13.10	14.78	13.37	13.53	9.65	14.00	10.37	13.28	9.38

Data source: China Statistical Yearbook

Table 9 Analysis sheet of the science and technology input of large and medium-sized energy enterprises over the years

		1995		1996		1997		1998		1999		2000		2001	
		amount	proportion	amount	proportion	amount	proportion	amount	proportion	amount	proportion	amount	proportion	amount	proportion
Coal mining and processing	government funds	9235	2.88	28448	5.27	15924	2.60	14930	2.03	40396	3.92	60237	3.33	33140	1.64
	Loans from financial institutions	34637	10.81	70797	13.12	97215	15.89	126075	17.15	120920	11.?4	268225	14.83	136500	6.75
	Corporate funds	233752	72.98	413903	76.72	491575	80.33	590236	80.31	856424	83.16	1459757	80.73	1842430	91.18
	Other funds	42674	13.32	26326	4.88	7226	1.18		0.00		0.00		0.00		0.00
	total	320298	100.00	539474	100.00	611940	100.00	734926	100.00	1029829	100.0e	1808225	100.00	2020740	100.00
Oil and natural gas extraction	government funds	190203	9.68	582233	22.59	163981	6.85	506377	20.14	541236	21.47	16040	0.55	3620	0.13
	Loans from financial institutions	36430	1.85	66320	2.57	2900	0.12	47940	1.91	33870	1.34	46000	1.57	49230	1.73
	Corporate funds	1613071	82.05	1799161	69.81	2024508	84.52	1899082	75.54	1866442	74.03	2635076	89.87	2753460	96.56
	Other funds	126175	6.42	129552	5.03	203814	8.51		0.00		0.00	153	0.01		0.00
	total	1965879	100.00	2577266	100.00	2395203	100.00	2513998	100.00	2521360	100.00	2932193	100.00	2851630	100.00

Oil processing and coking	government funds	90267	6.45	78787	4.69	53713	3.37	91869	6.06	317447	17.83	55098	1.74	25120	1.31
	Loans from financial institutions	102611	7.33	64389	3.84	86307	5.42	22631	1.49	83007	4.66	512910	16.24	93500	4.86
	Corporate funds	1108501	79.16	1434347	85.47	1317116	82.64	1352678	89.29	1266421	71.12	2356089	74.60	1578720	82.04
	Other funds	98925	7.06	100676	6.00	136603	8.57		0.00		0.00		0.00		0.00
	total	1400304	100.00	1678199	100.00	1593739	100.00	151492l	100.00	1780755	100.0C	3158196	100.00	1924370	100.00
Power, steam, hot water production and supply	government funds	339030	39.84	116403	11.13	177484	11.59	497763	29.76	701159	37.12	30654	1.10	53880	1.65
	Loans from financial institutions	146197	17.18	68652	6.56	160900	10.51	30405	1.82	59472	3.15	170947	6.11	237970	7.29
	Corporate funds	349725	41.09	802894	76.75	1105436	72.20	1103061	65.94	1089925	57.70	2449237	87.57	2761740	84.65
	Other funds	16111	1.89	58173	5.56	87218	5.70		0.00		0.00		0.00	37200	1.14
	total	851045	100.00	1046122	100.00	1531038	100.00	1672755	100.00	1889087	100.0C	2796903	100.00	3262370	100.00
Coal gas production and supply	government funds	532	1.38	4602	10.06	957	1.75	16989	16.29	970	2.07	1525	1.81	3020	3.32
	Loans from financial institutio	3800	9.82	6985	15.27	2000	3.67	3300	3.16	1000	2.13	6350	7.54	6000	6.60

	ns														
	Corporate funds	34064	88.06	33431	73.09	51352	94.16	79244	75.97	43741	93.24	73185	86.93	80410	88.40
	Other funds	285	0.74	782	1.71	230	0.42		0.00		0.00		0.00		0.00
	total	38681	100.00	45740	100.00	54539	100.00	104303	100.00	46910	100.00	84185	100.00	90960	100.00
Amount of above five industries	government funds	629267	13.75	810473	13.77	412059	6.66	1127928	17.24	1601208	22.03	163554	1.52	118780	1.17
	Loans from financial institutions	323675	7.07	277143	4.7l	349322	5.65	230351	3.52	298269	4.10	1004432	9.32	523200	5.15
	Corporate funds	3339113	72.97	4483736	76.17	4989987	80.66	5024301	76.81	5122953	70.49	8973344	83.24	9016760	88.83
	Other funds	284170	6.21	315509	5.36	435091	7.03	0	0.00	0	0.00	153	0.00	37200	0.37
	total	4576207	100.00	5886801	100.00	6186459	100.00	6540903	100.00	7267941	100.00	10779702	100.00	10150070	100.00
Amount of all industries of the whole country	government funds	2709888	6.34	3199410	7.07	3147666	6.30	4404189	7.92	4966952	7.46	4320967	4.68	4105550	3.92
	Loans from financial institutions	7245471	16.95	8923339	19.71	8856456	17.72	8930962	16.05	839844l	12.62	9725606	10.54	9563590	9.14
	Corporate funds	30548927	71.48	31282248	69.11	34836892	69.70	40250404	72.34	51028990	76.69	74437093	80.66	88036490	84.11
	Other funds	2233389	5.23	1856658	4.10	3137732	6.28		0.00		0.00	662379	0.72	700860	0.67

	total	42737675	100.00	45261691	100.0C	i9978746	100.00	55639427	100.00	5654014S	100.00	92281375	100.0C	104665440	100.00
Proportion of energy industry in all industries ％	government funds	23.22	216.86	25.33	194.77	13.09	105.76	25‘61	217.85	32.24	295.14	3.79	32.40	2.89	29.83
	Loans from financial institutions	4.47	41.72	3.11	23.88	3.94	31.86	2.58	21.94	3.55	32.51	10.33	88.41	5.47	56.41
	Corporate funds	10.93	102.08	14.33	110.2C	14.32	115.72	12.48	106.18	10.04	91.91	12.05	103.2C	10.24	105.61
	Other funds	12.72	118.83	16.99	130.66	13.87	112.02		0.00		0.00	0.02	0.20	5.31	54.73
	total	10.71	100.00	13.01	100.0C	12.38	100.00	11.76	100.00	10.92	100.0e	11.68	100.0C	9.70	100.00

Data source: China Statistical Yearbook

Table 10 research fields of major scientific research institutions of energy industry

Scientific research institutions	Subordinate to	Main research fields
China Petroleum Group Engineering Research Institute	China Petroleum Group	Oil well cement additive, special terrain engineering materials and constructing technologies, pipe direct bury heat preservation technology, anti-corrosion coating and coating technology, storage tank and pipe automation technology, old pipe repairing technology, automation control technology and others.
China National Petroleum Corporation Pipe Research Institute	China Petroleum Group	Mechanical behavior of petroleum tube, environmental behavior of petroleum tube, malfunction diagnosis, prediction and prevention of the petroleum tube and corresponding services.
China Petroleum Group Economy and Information Research Center	China Petroleum Group	Information research and services (corporate strategic development research, corporate transnational operating service, latest information about oil technological advance and oil field production construction), network

		maintenance and resource development (developing information & technology service market), industrial service and management
China Oil Exploration and Development Research Center	China Petroleum Group	Fundamental theories of oil and gas exploration & development, development of advanced technologies and applications, technological researches
PetroChina Planning & Engineering Institute	China Petroleum Group	Planning, feasibility study, market development, economic evaluation, consultation and assessment, design inspection, construction cost management and other researches on the oil & natural gas exploration and development project.
Sinopec Oil Exploration and Development Research Institute	Sinopec Corp.	Development strategy, economic environment, policies and regulations, marketing management, decision-making consultation, scientific and technological information
Sinopec Oil Exploration and Development Research Institute	Sinopec Corp.	Oil & gas exploration and development strategy, proactive basic theory and applied technology research of exploration & development, resource evaluation research, reserve engineering technology research, technical economy demonstration of significant projects and design inspection, etc.
Sinopec Oil Chemical Scientific Research Institute	Sinopec Corp.	Raw oil assessment and oil processing procedure scheme, petroleum refining and processing technique and catalyst, oil goods and additives, oil and chemical analysis and test identification, oil chemical automation technology and other researches.
Sinopec Beijing Chemical Research Institute	Sinopec Corp.	Focusing on the R&D development and hi-tech exploring research of petrochemical industry applied technologies, having formed four strong areas composed of ethylene technology and organic chemical engineering, polyolefin catalyst and technique research, plastic modifying and processing application and chemical engineering environment protection, of which oil chemical engineering catalyst and industrial application have reach the international level
Sinopec Fushun Petroleum Chemical Research Institute	Sinopec Corp.	Development of catalytic hydrogen technology, asphalt and petroleum wax product, refinery tail gas comprehensive utility, petrochemical engineering and oil

		field environment governing technology development and environment inspection, bioengineering technology development, raw oil assessment, and oil wax and petrochemical engineering environment analysis standardization and others.
Sinopec Shanghai Petroleum Chemical Research Institute	Sinopec Corp.	Development, exploration and application of petrochemical catalysts and development of its complete technologies, fine chemical engineering, macromolecule synthesizing and processing research, development and application, research and development of chemical engineering, and studies on the computer process control software, etc.
China Electric Power Research Institute	State Power Corporation	Electric system analysis and control, transmitting/distributing power and node technological engineering, power station automation, grid and converting station automation, communications and information technologies, etc.
State Power Corporation Thermal Power Research Institute	State Power Corporation	Thermal power machine set operating technology, power station automatic control technology, clean coal power generating technology, new energy power generation technology (including nuclear power plant conventional island and geothermal power generation technology), thermal power unit auxiliary engine and R&D of other areas.
State Power Corporation Electronic Automation Research Institute	State Power Corporation	Relay control, grid control, automatic control, system stability technology, industrial and electrical control, dam and project monitoring, water regime, water allocation and environment monitoring, power distribution terminal technology and researches on other areas.
Electric Power Construction Institute	State Power Corporation	Circuit structure, wire fitting, welding technology, constructing machine, technical economy and standard, electric power building projects and researches on other areas.
State Power Corporation Wuhan High Voltage Research Institute	State Power Corporation	High-voltage power transmission and distribution

State Power Corporation Suzhou Nuclear Power Research Institute	State Power Corporation	Nuclear power construction technology, nuclear operating technology, nuclear safety, and nuclear power station refueling engineering environmental influence assessment, etc.
China Institute of Water Resources and Hydropower Research	Ministry of Water Resources, State Power Corporation, Council Mainly Comprising Chinese Academy of Sciences, chair man-in-charge system directed by board of directors	Water source, water environment, structural seismic resistance, remote sensing, river reservoir silt, dam structure, new material, geotechnical engineering, thermal and nuclear power cooling water, hydropower station computer control, engineering safety monitoring and defect processing, hydropower station speed regulation, excitation and unit automatic component, etc.

Data source: China Electric Power Yearbook

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