Transition strategy of the transportation energy and powertrain in China

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Abstract

The problems of the transportation energy and environment are the major challenges faced globally in the 21st century and are especially serious for China. The future 20 years is the strategic opportunity period of the transition of the transportation energy and powertrain system for China. The greatest characteristics of hydrogen economy lie in its diversity of the primary energy source, the unification of energy carrier and the greening of energy transformation. Development of hydrogen energy transportation powertrain system is suitable for China from the views of the situation of Chinese resources and energy sources, the urban and rural layouts, the superiority of later development and the successful practices of clean cars and electric vehicle development projects. The transition of the transportation energy powertrain system includes three parts: the transition of the energy structure, the transition of the powertrain system and the transition of the fuel infrastructure. The technical pathways of energy powertrain system transition includes expending the use of gaseous fuel to prompt the multiform of the transportation energy and to prepare for the transition of the infrastructure simultaneously, developing and promoting the hybrid technology to solve the current energy and environment problems and to prepare for the transition of powertrain system, and focusing on the research and development and demonstration of fuel cell vehicles and the hydrogen energy technology to prompt the earlier formation of the market of fuel cell vehicles. The goal in the near and medium term of transition is to reduce the fuel consumption by 100 million ton in 2020 by substituting and saving, and the long-term goal is to setup the infrastructure of hydrogen and fuel cell vehicle as the main one replacing the petroleum internal combustion engine vehicle. In order to realize the strategic goals of the transition, the four-phases strategic periods and research and development activities are discussed and proposed.

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1. The strategic choice of transportation energy and powertrain system

1.1. Challenges and opportunities

1.1.1. The energy and environment problems

The problems of the transportation energy and environment are the major challenges faced globally in the 21st century. The amount of registered car and truck/bus in 2003 are approximately 589 million and 224 million worldwide, respectively, which are increasing at the rates of 2.7% and 3.0% annually, respectively, between 1993 and 2003 (Davis and Diegel, 2006a). With this increasing

speed, it is estimated that the total vehicle amount would be nearly 1 billion globally by the year 2010. According to the long-term estimation made by the Department of Energy (DOE) of the United States, the global amount of vehicles will increase to 3500 million by the year 2050. And the amount in the developed countries will be doubled while that in the developing ones will increase about 15 times. The statistical data (International Energy Agency, 2005a) showed that 57.8% of the global petroleum consumption was in the area of transportation in 2003 and was 66.6% in the US in the same year (Davis and Diegel, 2006b). It is estimated that the oil used in transportation would account for over 62% in the total global consumption of petroleum by the year 2020. According to the estimation (Birky et al., 2001) of the research of DOE of the United States, there will be net
shortage between the global demand of petroleum and the normal petroleum supply after the year 2020. The net shortage would reach 50 billion barrels by the year 2050, which is nearly twice that of the total output of petroleum in the year 2000. Simultaneously, the consumption of the transportation energy is also one of the main sources that cause the local environmental pollution and the discharge of the global greenhouse gases. Therefore, a consensus has been reached globally: the reform of the transportation energy is unavoidable.

The energy and environment problems are especially serious for China. The auto industry has been developing very fast in China in recent years. The production of autos in China was 5.70 million in the year 2005, which made China rank at No.4 in the world (QICA Statistics, 2005). Various kinds of domestic and international estimations (Chen et al., 2004; Feng, 2005; Pemberton, 2004; Xu, 2006) show that China might probably exceed the US to become the biggest market country of autos in the world by the year 2020. The amount of autos every one thousand people is very low, it was only 19 autos per 1000 person in 2004, which was only 2.5% that of the US in 2003, and was just equal to that of the US in year of 1914 (Davis and Diegel, 2006c). This makes it the largest country in terms of potential auto market. It is estimated that the amount of autos would reach 130–150 million by the year 2020 (Chen et al., 2004). However, China has just reached the threshold of an auto society. The ratio of the petroleum consumption used in autos in the total consumption of the petroleum is nearly one third, which is still much lower than the average amount of the world (over one half). And China has already felt the huge challenge of the ever increasing jitter and the safety of petroleum. In the meantime, the air pollution and the emission of CO₂ caused by petroleum consumption used in autos have become more and more serious problems. China has become the second largest country in the emission of CO₂ (International Energy Agency, 2005b), which would result in more and more fierce international political and economic disputes. All this fully shows that the transportation energy problem faced by China has become fiercer, more influential and more serious. If the transportation energy power system is developing in the traditional way, the supply of petroleum in China can hardly go on, thus the realization of the transition of energy power system in China is the general trend of events.

1.1.2. Opportunities

The future 20 years is the strategic opportunity period of the transition of the transportation energy and powertrain system in China. Historically speaking, the change of the transportation energy power system has always been at the core position of the technical revolution and the economic transition. In the 19th century, coal and the steam engine trains prompted the industrial revolution in Europe and they have created the industrial economy and industrial civilization. In the 20th century, petroleum and the internal combustion engine automobiles prompted the economic takeoff of the United States and have brought the mankind into the economic system and the material prosperity based on petroleum; but they have also caused the deterioration of the energy and environment. Entering the 21st century, the rapid development in the information technology represented by the Internet, the biotechnology represented by Gene, the new material technology represented by Nano and the new energy technology represented by hydrogen fuel cell, has predicted a new technological revolution and an economic transition. Especially the technology of hydrogen fuel cell has an important position in the technology revolution because of its systematical characteristics and its integration to other high and new technology. Viewing from the current developmental trends, important breakthroughs will be realized in the global high and new technical revolution in the first 20 years of the 21st century and the mankind will be brought into the post-industrialization times of the sustainable development before the middle of the 21st century.

With the development of the high and new technology, the technical reforms of the various kinds of the traditional industries are developing comprehensively. Especially, facing the huge pressure of energy conservation and environmental protection, the technical reform and transition of the transportation energy powertrain system have been developing very fast. Its major trend is the diversification of the energy and the electrification of the power. Hydrogen energy, as an energy carrier like electricity, is easy to solve the problem of the fuel infrastructure brought about by the energy diversification and it can transfer the different energy into a unified fuel. Therefore, it has become the best choice of a new generation of pilot-typed fuel used in autos. Fuel cell, as a kind of chemical to electrical energy transformation device of high efficiency with no pollution, is considered the optimal choice of the core part of the electrification of auto power. Hydrogen fuel cell, as the transition goal of a new generation of auto energy powertrain system, has been favored globally. The breakthrough of the “mobile” fuel cell powertrain system used in cars represented by Proton Exchange Membrane (PEM) fuel cell has also brought about the development of using the “stationary” fuel cell system to generate electricity. In the long run, the “stationary” and the “mobile” fuel cell systems would couple interactively. And the two kinds of energy carriers, hydrogen and electricity, would supplement each other to form an integrated energy powertrain system and constitute the future foundation of the hydrogen economy. For this reason, in major countries all over the world, political leaders of the government act as the head, integrate human and material resources nationwide to promote the research and development plans of the hydrogen fuel cell transportation energy powertrain system with all their efforts and plan to transit to the hydrogen economy.

It wills still a quite long process when a radical transition of the energy powertrain system, and the transition to the
hydrogen economy are finally realized after people have made continuous and persistent efforts. According to domestic and international studies, it is estimated that the large-scale commercialization of cars with fuel cell will happen around the year of 2020, and the ultimate hydrogen economy will be realized between 2040 and 2050 (United States Department of Energy, 2002; European Commission, 2003; Toshiaki ABE, 2003).

In order to realize the goal, it is necessary to overcome a series of technical and economic challenges (National Research Council, 2003). Therefore a transition process is needed. That is, in recent years, petroleum fuel will still occupy the leading position. From the year 2010, the times of diversifications will begin for auto fuel, and the non-petroleum fuel will be combined with petroleum fuel to obtain large-scale commercial application. And starting from 2020, the hydrogen fuel based on diversified energy sources will gradually ascend to be a leading type of fuel. Corresponding to such a situation, the auto powertrain will gradually change from the internal combustion engine to a hybrid powertrain, the hybrid of the internal combustion engine/electric motor/battery, and then to the powertrain of hydrogen fuel cell.

The greatest characteristics of hydrogen economy lie in its diversity of the primary energy source, the unification of energy carriers and the greening of energy transformation. It can promote the smooth transition from the fossil energy to the renewable energy and the realization of the dispersion of energy supply and the purification of the discharge (including the concentrated treatment of CO$_2$). The process of hydrogen energy replacing petroleum will bring about three great changes:

1. The change of the energy structure, which will change the strategic layout of the current energy distribution in the world.
2. The transform of the auto powertrain technique, which will ultimately abandon the traditional internal combustion engine that has lasted for over 100 years.
3. The reconstruction of the energy infrastructure, the distribution type of manufacturing and supplying hydrogen will change the traditional pattern of oil barons monopolizing energy supply.

These changes will not only cause large-scale of industrial changes and economic changes, but also will influence the political and diplomatic layout in the world. Such a technological revolution provides historical opportunities for the transition of the transportation energy powertrain system in China and also brings about new challenges. China should grasp such strategic opportunities, steadily promote and realize the transition of our transportation energy powertrain system.

1.1.3. Conditions and the foundation for the transition

The situation of China’s resources and energy sources is suitable for developing hydrogen energy transportation powertrain system. China lacks oil, has little natural gas, but is rich in coal. Such structural characteristics bring serious challenges for the sustainable development of the transportation energy sources. Hydrogen, as an energy carrier, can be obtained from coal, nuclear energy and various renewable resources, and can also be obtained by using low-peak electric energy and byproducts of industries. Such practice is beneficial for the realization of the diversity of the sources of transportation energy and for the sustainable development of auto industry.

Hydrogen energy is suitable for China from the view of urban and rural layout. In the urban modes, the large city group is the main feature and the infrastructure of auto fuel is quite concentrated. And relative to the foreign infrastructure spreading all over the country, transition is easier to be realized for China. In the broad countryside, there are different resources features of the primary energy source in different regions, so it is better to develop the hydrogen fuel infrastructure with the diversity of primary energy, the localization of hydrogen production, and the network distribution of the supply.

In addition, when hydrogen is combined with highly efficient fuel cell, the transition efficiency will be greatly raised, and thus the comprehensive efficiency of the transportation energy powertrain system from the primary energy to the output of the auto power will be greatly raised. For example, according to the fuel cell passenger car testing results carried out by Chinese researcher (Wan, 2004; Wan, 2006), the fuel consumption is 0.95 kg hydrogen which is 3.51 of petrol equivalent for 100 km. The 8 million ton hydrogen production annually today in China could satisfy the energy demand of 6.6 million fuel cell cars. And if the hydrogen is produced from the coal, it is estimated that the demands of raw coal is about 90 million ton.

China has the superiority of later development in realizing the transition of the transportation energy powertrain system. Viewing from the auto developmental stage, China does have such superiority. Although the governments of developed countries actively promote the transition of the powertrain system of auto with hydrogen energy fuel cell, but they must face vast challenges, especial the higher transition cost due to the huge traditional car industry, perfect exiting petroleum infrastructure, and the consumption habits, therefore the great difficulties in executing the transition. For contrary, the auto industry has just started in China, the rate of its popularization is low; therefore, there will be greater free extent in terms of the strategic choice of the development of the auto powertrain system. Simultaneously, the industrialization and system for the new energy auto has not formed and completed worldwide, and China is basically on par with foreign countries in the R&D and industrialization of the new energy autos; China has the greater comparative advantages in new energy autos relative to the traditional autos. If the policies is proper, it is quite possible to realize the transition in the world firstly and thus to realize a frog-leap of development in China.
Otherwise, if the opportunity could not be grasped, the later development advantage would become the later development disadvantage.

The realization of the transition for the auto powertrain system is the strategic summary and inevitable requirement from the successful practice of clean cars and electric vehicle development projects. Based on the strategic consideration of China’s energy safety, environmental protection and the realization of the frog-leap development of auto industry, the Ministry of Science and Technology, together with related ministries and commissions, organized and executed the “Program of Clean Cars” during the period of the ninth five-year plan. Significant stage achievements have been attained (Wang, 2005). Up to 2005, there are 250 thousand vehicles operated by natural gas or LPG, and more than 700 gas-stations all over the country. 1.3 million ton of petroleum is replaced annually. Moreover, there is a rapid increase trend in autos operated by natural gas. It is expected that the next several years will be a stage of the large-scale of popularization and application of these vehicles.

During the period of the tenth five-year plan, the Ministry of Science and Technology has organized and executed the national high-technology major project on electric vehicles, one of the largest technology developing projects in key technologies R&D programme. This project budget is about 880 million RMB, more than 2000 scientists and experts from about 200 universities and companies directly participated in its execution (Wan, 2006), and a cooperation mechanism has basically formed between the government, industries, universities and research institutions. Now the small type of pure electric vehicles had passed the product certification test and hybrid cars have begun commercial demonstration operation. For fuel cell vehicles, some practical prototype platforms have been developed and the commercial demonstration operation will soon begin. Various kinds of electric vehicles have entered the practice testing stage. All of these have laid a sound foundation of technologies, talents and practice for the execution of the strategy of transition of auto powertrain in China.

In summary, it is believed that China possesses the possibility of developing the hydrogen energy fuel cell powertrain system used in autos.

2. Target and schedule

2.1. The main content of the energy powertrain system transition

The transition of the transportation energy powertrain system includes three parts. The first part is the transition of the energy structure, the transfer from fossil fuel energy such as petroleum, natural gas and coal-based fuel, to the hydrogen energy with the production from diversified energy such as the fossil energy, the nuclear energy and renewable energy, should be realized gradually. The second part is the transition of the powertrain system, promoting the transition from traditional internal combustion engine to advanced gas internal combustion engine and hybrid powertrain technology, then transfer to the innovation technology of the fuel cell powertrain system. And the third part is the transition of the infrastructure, including the research and development of the safe, high efficient and affordable technologies of hydrogen storage, delivery and refueling.

2.2. The technical pathways of energy powertrain system transition

The fundamental technical pathways for realizing the energy powertrain system transition lies in the following:

(1) Expending the use of gaseous fuel to prompt the multiform of the transportation energy and to prepare for the transition of the infrastructure simultaneously.

It has two advantages by expending the use of gaseous fuel vehicles. One is that it is benefit to utilize the relative plenty natural gas resources, reduce the oil demands thus relax on the dependence on import oil, even get rid of the dependence on petroleum in the future. And on the other hand, the relevant technologies, infrastructures, codes and standards, and systems formed or built up in this process will lay a foundation for realizing the transition of the infrastructure for hydrogen energy in the future.

(2) Developing and promoting the hybrid technology to solve the current energy and environment problems and to prepare for the transition of powertrain system

The hybrid powertrain system is very suitable for energy saving and environment protection. It can meet the requirements of the vehicle power and comfortable performances. Its average fuel consumption can be reduced over one third, thus great improvement in the fuel economic performance and reduction of the CO2, the criteria pollutions will be reduced greatly. In the meantime, the development of the hybrid powertrain vehicle will also promote the improvement of the technology of motor and the battery; promote the development of these newly rising industries and laying a solid foundation for the transition of the fuel cell vehicle powertrain system. The hybrid powertrain system will be developed by the following pathways. First is the petroleum-electricity hybrid (gasoline (diesel) internal combustion engine/electrical motors/battery), second is the gas–electricity hybrid (gaseous fuel internal combustion engine/electrical motors/battery), and finally to the electricity–electricity hybrid (fuel cell/electrical motors/battery).

(3) Focusing on the research/development and demonstration of fuel cell vehicles and the hydrogen energy technology to prompt the earlier market formation of fuel cell vehicle

Emphasis is put on the research, development and industrialization of integration technologies of the hydrogen fuel cell vehicles and the key components or parts, establishment of the technical standards/codes and the
safety regulations of the fuel cell vehicles, research of the hydrogen storage and delivery technologies and demonstration of the hydrogen fuelling station, promotion of the commercialized demonstration of fuel cell vehicles and gaining more experience in its operation and management, realization of the industrialization and commercialization of the fuel cell vehicles gradually.

2.3. Goals and executive schedule of the energy powertrain system transition

2.3.1. Goals of the energy powertrain system type-transfer

According to the above technical pathway, the goals of transition of the transportation energy powertrain system could be defined as the near-middle term goal and long-term goal.

(1) The goal in the near-middle term: Through the technical progress and the policy guidance, the popularized applications of various kinds of energy-saving autos represented by the hybrid power vehicle are realized. Thus the fuel consumption can be reduced largely. It is expected that one third of the average annual fuel consumption per vehicle is reduced. In recent year, the average annual fuel consumption per vehicle is about 1545 kg gasoline equivalent (Ouyang, 2006), and that of Japan and France are 1000 and 1200 kg, respectively. With one third reduction, the fuel consumption for one vehicle with in one year in the year 2020 in China will be about 1000 kg, which is equivalent to the levels of those of Japan and Europe now. If the autos amount of 150 million in the year 2020 is taken into account, about 70 million ton of petroleum will be saved.

In the other hand, the large-scale application of various kinds of new energy vehicle, including the gaseous fuels and the hydrogen-fuel cell vehicles, would be realized. By the year 2020, it is suggested that the share of the non-petroleum fuel in the total consumption of auto fuel would reach over 20%. Thus, approximately 30 million ton of petroleum fuel could be altered by the coal based fuel, natural gas based fuel, biomass based fuel and hydrogen.

The two mentioned above together would reduce 100 million ton of the consumption of petroleum in the year 2020.

(2) The goal in the long-term /final goal: The final goal of this transfer is to set up the infrastructure of hydrogen fuel. Due to its ecological characteristics such as the zero emission, renewable energy, recycle material and intelligent transport, the hydrogen fuel cell vehicle would become the main one by replacing the petroleum internal combustion engine vehicle. They would form the foundation of hydrogen economy together with the distributed power generating system.

2.3.2. Executive schedule of the energy powertrain system transition

In order to realize the above strategic goals of the transition for the transportation energy powertrain systems, the strategic periods could be divided into four phases.

(1) The first phase (before 2008): The self-developing ability of the energy-saving internal combustion engine vehicles will be established and the gaseous fuel vehicles would be popularized. The goal of the scale commercialization of petroleum-electricity hybrid vehicle will be realized. The mainstream technologies of the powertrain system of hydrogen fuel cell vehicle are formed and the commercial demonstration of the fuel cell vehicles and the relevant hydrogen infrastructure is realized in major cities, e.g. Beijing and Shanghai.

(2) The second phase (before 2015): The scale commercialization of the gas-electricity hybrid vehicle will be realized and the mature sets of the technology of the hydrogen fuel cell powertrain system will be formed. The fuel cell city buses have the commercial competitive ability and will be used in batches in urban transport. Based on the gaseous fuel supply infrastructure, the hydrogen fuelling station networks will be built in some large cities and the hydrogen expressways will be demonstrated.

(3) The third phase (before 2020): The fuel cell cars have the commercial competitive ability and the scaled commercial application is initiated. Based on the infrastructure of gas fuel, the filling station and networks of hydrogen fuel are constructed in main cities around the country. Large scale hydrogen production by means of coal reform and the nuclear energy are conducted. Combined with the wide application of hydrogen fuel cell in electrical power, households, electrical appliances and the national defense, dozens of hydrogen energy communities are formed.

(4) The fourth phase (after 2020): The transportation energy powertrain system with the hydrogen energy fuel cell acting as the core is ascending gradually to be the leading type of the power system of the transportation energy source. And the methods of producing hydrogen gradually become multi-element and are transferring toward producing hydrogen using renewable energy. The goal of hydrogen economy will be attained by the year 2050.

3. Projects and policies

The transition of the transportation energy powertrain system is a long term and complex activities. It needs the cooperation between government, research institutes and industries not only inside one nation, but also worldwide. As a developing country, China would focus on the some key technologies and play the proper role based on its basic situations to promote the transition to the hydrogen economy.

3.1. Research and development activities

3.1.1. Research and development key points

Based on the new generation of highly efficient, clean and intelligent internal combustion engine, emphasis is put
on the breakthrough of the key technology of the hybrid power of the ICE/electric motor/battery.

Based on the natural gas engines, emphasis is put on developing the hythane (a blend of hydrogen and natural gas with 20% or less hydrogen by volume) internal combustion engine technology and corresponding hybrid technology.

To conduct the fundamental study and application development of key materials and parts of fuel cell, fuel cell stack and modules, emphasis on developing a new generation of fuel cell engines and their hybrid power.

To develop the integrated technology with the hydrogen energy powertrain system and to develop fuel cell vehicles with the market competitive ability.

Emphasis in the technology development of the hydrogen production from natural gas, coal, and by nuclear and renewable energy.

Focus on the development of relevant patents, codes and standards, so as to form corresponding policy.

3.1.2. Key technologies R&D programme

The transition of the transportation energy powertrain system is a deep technological revolution. At the early stage of the transition, the guiding role of the government and the financial support of the state are very important. In the US, Europe and Japan, heads of the government lead the program personally and the states put in large amounts of funds to launch enormous plans of research and development. For example, in America, in 2003, President Bush announced a $1.2 billion (Bush, 2003) Hydrogen fuel initiative to reverse America’s growing dependence on foreign oil by developing the technology needed for commercially viable hydrogen-powered fuel cells. Through partnerships with the private sector, the President’s hydrogen fuel initiative seeks to develop hydrogen, fuel cell, and infrastructure technologies needed to make it practical and cost-effective for large numbers of Americans to choose to use fuel cell vehicles by 2020; in Japan, the government has put 63.6 billion Japanese yuan, nearly 600 million US dollars, (Ando, 2005) in the Prime Minister’s Project—JHFC from 2003 to 2004, focus on the powertrain system of hydrogen energy fuel cell development and demonstration. Even the government of the Republic of Korea has also drawn up a national plan and has decided that 650 billion of Korean yuan, nearly 560 million US dollars, (Seong, 2005) will be spent on the R&D of the hybrid power and fuel cell autos to the year 2010.

In China, the new generation of the transportation energy powertrain system has been considered in the Chinese Science and Technology medium-and-long term planning. In the next 15 years, one new key technologies S&T programme will be launched focusing on the next generation clean energy vehicle technologies including the following contents:

- One core system: energy powertrain system.
- Two production platforms: energy-saving vehicle and new energy vehicle.
- Three key technologies: Automotive electronics technology, light-body technology and clean combustion technology

3.1.3. International cooperation

China would use the excellent opportunities which the whole globe looks favorably at China’s superiority of later development, and opportunities of the 2008 Beijing Olympic Games and the 2010 Shanghai World Expo to carry out the international cooperation widely and actively with various countries, especially with the USA, EU, Canada and other IPHE members, in the field of hydrogen and fuel cell developments.

3.2. Demonstrations

(1) Policy and regulation: Relevant policies and regulations should be established so as to solve the difficult problem of demonstration. The procedure of examination, approval and management regulations on the announcement of auto products with new energy and on the market access should be studied and drawn up. Thus problems of the model operation of new energy autos and the license issue of the test operation with passengers can be solved. Standards, codes and procedures of examination and approval on the construction and operation of the infrastructure of the new energy source should be drawn up.

(2) Demonstration partnership: The initiative of many sides should be brought into play and various kinds of demonstration partnership will be composed. To construct demonstration partnership is an important means of promoting the transition toward the hydrogen energy transportation. For example, the CaFCP in California, US, the CUTE of the EU and the JHFC of Japan are all led by their central governments and including the energy company, auto industry and local government. The 2008 Beijing Olympic Games and the 2010 Shanghai World Expo create the best opportunities to construct the demonstration partnership of hydrogen energy transportation in Beijing and Shanghai.

(3) Government as the pilot role: Owing to the objective phenomena that the price of the new generation of fuel cell powertrain system is rather high in the phase of demonstration and the recognition degree of the public is low, the government can lease or purchase the vehicle and officials take the lead in trial driving.

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