Fuel Cell Vehicle Development in China

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Hydrogen fuel cells (FCs) are one of the most promising new technologies of the 21st century for electricity generation. Because a fuel cell directly converts the chemical energy of hydrogen fuel to electrical energy without burning the fuel, the process is much more efficient, as well as cleaner and safer, than any currently available conventional technology, including thermal, large hydropower and nuclear power generation. At some time during this century, fuel cells, together with renewables, could replace most existing thermal power generation capacity and eliminate the need for direct burning of fossil fuels and fossil-derived liquid fuels, such as gasoline, diesel, and fuel oil. Industrialized country governments and companies have invested tens of billions of dollars in the development and commercialization of fuel cells. China needs to recognize and understand the profound changes that fuel cell technology may bring to the world's fossil fuel-dependent economy, so as to avoid potential adverse economic impacts. Instead, with foresight and careful planning, China could benefit immensely from this technological revolution.

One Stone to Kill Four Birds

Our knowledge of fuel cells dates back to 1839, when British scientist Sir William Grove first demonstrated the basic principles of a fuel cell. One hundred twenty years later, in 1959, Francis Bacon of Scotland built the first real fuel cell, which had a 6 kW capacity. Since then, fuel cells have been used in a number of space and military missions, although they have emerged in civilian applications only during the last decade.

While the underlying principle of a fuel cell is very simple, the successful application of the principle involves overcoming both technical and economic barriers. On the technical side, particularly for vehicle utilization, one has to be able to start the fuel cell reaction quickly, keep it going at a sufficient rate, and stop it promptly whenever needed. These rapid control specifications will require the identification of good fuel cell catalysts. The handling of hydrogen - the lightest element on Earth – poses substantial challenges as well. Hydrogen production, transportation, and storage require special research attention because the properties of hydrogen gas are very different from those of traditional liquid fuels. On the economic side, while platinum is an excellent fuel cell catalyst, the metal is an expensive component for fuel cell vehicles (FCVs), at least as currently designed. A fuel cell vehicle is currently ten times more expensive than a common passenger car, although its cost has gone down 100 times over the past 10-15 years, and will surely continue to decrease as automakers develop lighter, more efficient vehicles designed to take full advantage of fuel cell technology.

Fuel cells and fuel cell vehicles offer four major benefits as well as four specific advantages for China. The major benefits of fuel cell technology are:

- high energy conversion efficiency (some fuel cells types reach 60 percent);
- suitability for distributed power generation;
- near-zero emissions, including CO_2; and
- ability to utilize a variety of fuel sources (e.g. natural gas, gasified coal, renewables, industrial hydrogen, and water electrolysis).

A fuel cell vehicle is superior to an electric battery vehicle because batteries have short lives, require frequent recharging and contain heavy metals that can cause serious environmental contamination if not managed properly. For China, developing fuel cell vehicles would be like using one stone to kill four birds. The specific advantages of FCVs for China include enhanced energy security, greater industrial competitiveness, improved urban air quality and reduced greenhouse gas emissions.

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Enhanced Energy Security: First, the wide application of FCVs would reduce China's growing dependence on imported oil, thus increasing its energy security. China's oil reserves are limited: on a per capita basis, the country's proven reserves in 2001 amounted to 2.6 tons per person, only 11 percent of the world's average per capita level. China was a net crude oil exporter until 1993, but since then oil imports have increased sharply, reaching over 75 million tons in 2000. This accounted for almost 34 percent of the country's total oil consumption in that year, exceeding the 30 percent limit on imports that China believes necessary to protect its energy security.

In 2000, vehicles in China consumed 21 percent of the national total crude oil consumption. This represents an increase of 7.2 percent over the previous year, much higher than the annual national average energy consumption growth of 4-5 percent. The increase in vehicle oil consumption was even higher in major cities. Beijing's gasoline consumption, for example, increased by more than 12 percent from 1998 to 1999.

Several domestic and outside projections indicate that China's oil demand from vehicles will grow 57 percent from 2000 levels by 2010, and 100 percent by 2020. In this case, China would need to import 160 - 210 million tons of oil by 2010, some 45-55 percent of its total annual oil demand, while by 2020, imports may reach 240 – 360 million tons, accounting for 60-70 percent of the total demand. In such a situation, any fluctuation of the international oil market could seriously disrupt China's economy.

The government is currently trying to develop liquefied coal as a substitute for oil, but this alternative would produce even more air pollution than crude oil products. Hydrogen fuel cells offer a much better approach to reducing China's reliance on oil. If only ten percent of China's vehicles were FCVs, its annual crude oil consumption would be reduced by 15 million tons.

Greater Industrial Competitiveness: Second, FCV technology offers China's automobile industry a unique opportunity to improve its competitiveness in the increasingly global automobile market. The number of civilian vehicles in China is estimated to increase by an average of 10 percent per year, from 18 million in 2001 to 40 million in 2010 and 75 million in 2020. China's entry into the World Trade Organization will open the door for foreign companies to compete with China's national auto industry for this domestic market. The world's major automakers have spent decades working to improve the design and manufacture of traditional internal combustion engines, and Chinese companies lag far behind them in these traditional technologies. With FCVs, however, the technology gap between China and industrialized countries is narrower, because FCV technology is not yet mature and the FCV market is only beginning to emerge. Given China's impressive record in fuel cell research over the past three decades, it still possible for China's auto industry to develop, through dedicated effort, into a world-class center for the design and manufacture of clean, advanced vehicles.

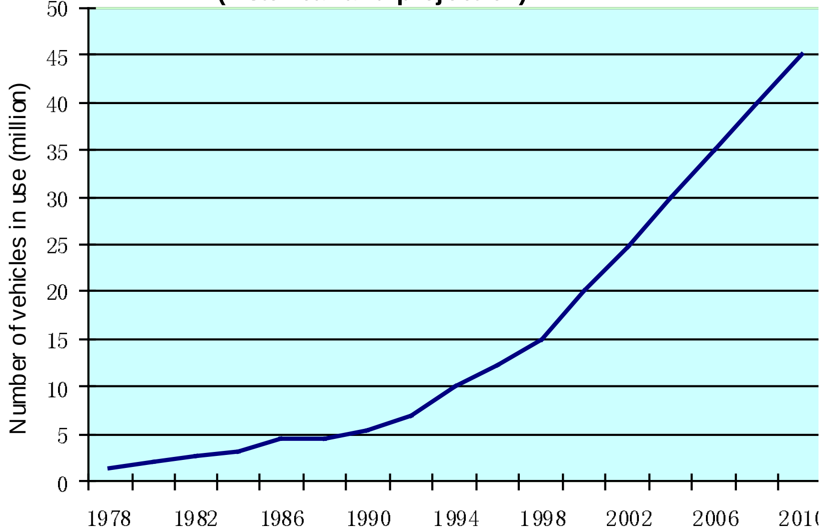
Improved Urban Air Quality: Third, widespread use of FCVs would greatly improve China's poor urban air quality. The number of vehicles in China has been increasing exponentially in recent years (Fig.1). Vehicle exhaust has become the main source of pollution in China's megacities, including Beijing, Shanghai, and Guangzhou. CO and NOx emissions from the transportation sector now together account for over 60 percent of total urban air pollution. Switching only 25 percent of Beijing's 12,700 diesel buses to fuel cell buses would eliminate 485 tons of carbon monoxide, 1,800 tons of NOx, and 1,600 tons of SO_2 each year.[2]

Reduced Greenhouse Gas Emissions: Finally, fuel cell vehicles offer China an effective means of fulfilling its obligations under the Framework Convention on Climate Change.[3] China is a party to the Convention and has also ratified the Kyoto Protocol. While as a developing country China is not required to accept a CO_2 reduction target and timetable under the current terms of the Kyoto Protocol, its sheer size –

[2] Communication with China Energy Research Institute (2002)

[3] The Convention stipulates "All parties …… shall formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removal by sinks of all greenhouse gases…"

Fig. 1 Trend in Total Civilian Vehicles in Use in China (historical and projection)



Source: The State Science and Technology Commission of China, "Project Report to the United Nations Development Programme: Study of Fuel Cell Buses Commercialization Potential in China", Project no. CPR/96/313 (1998).

economically, geographically and demographically – ensures a global impact from almost everything China does. The International Energy Agency estimated in 2002 that by 2020, China's CO_2 emissions would increase by 77 percent over the 2000 level.[4] Interestingly, while the IEA estimated that the share of CO_2 emissions from power plants and industrial facilities would remain the same at 75 percent, it predicted that contributions from the transportation sector would increase from 8 percent in 2000 to 12 percent by 2020. Promoting FCVs and other fuel cell applications in China would cut emissions and at the same time allow the country to benefit economically from this technology.

Started early but fell behind

China began its fuel cell research 45 years ago. The Dalian Institute of Chemical Physics under the Chinese Academy of Science (CAS) embarked on fuel cell research in 1957, and by the end of the 1960s had successfully developed two types of asbestos membrane alkaline fuel cells for space applications.[5]

In 1990, the Changchun Institute of Applied Chemistry at CAS began to study proton exchange membrane fuel cells (PEMFC). This research emphasized catalyst and electrode preparation, but also included methanol reforming. The result of this study was a 100 W PEMFC prototype.[6] Over the years, the Dalian Institute of Chemical Physics developed a series of 1 - 5 kW PEMFC prototypes.[7] More recently, the institute built a 30 kW FC stack, which was integrated into a hydrogen-fueled bus for research and demonstration purposes in January 2001.[8] Throughout the 1990s, over a dozen Chinese institutions and universities were

[4] International Energy Agency, "2002 World Energy Outlook – China Energy Outlook" (2002)

[5] The State Science and Technology Commission of China, "Project Report to the United Nations Development Programme: Study of Fuel Cell Buses Commercialization Potential in China", Project no. CPR/96/313 (1998)

[6] Ibid.

[7] Global Environment Facility (GEF)'s project document "Demonstration for Fuel Cell Bus Commercialization in China" (July 2000)

[8] Mao, Z. Q., "China's Fuel Cell Vehicle Development Status and Problems", presentation at the Beijing Fuel Cell Commercialization Seminar, organized by the Energy Research Institute and the Natural Resources Defense Council (Oct. 2002)

involved in research and development on a variety of fuel cell types.

China's spending on fuel cell research, however, has been small and irregular, not comparable to the level of investments exemplified by the United States and other industrialized countries. Moreover, the funding was spread thinly over too many institutions and too many topics, resulting in an overall weak national effort in fuel cell development. While China possesses a strong pool of research scientists, it is traditionally weak in putting these technologies into use, and weaker still at commercializing research results. In fact, there exist no truly effective mechanisms in China to push scientific and technological research achievements onto the market. Fuel cell research has faced the same problems. Some institutions, such as the Dalian Institute of Chemical Physics, were once at the forefront of world fuel cell research, but their research achievements have stayed in the laboratories without being further developed for commercial purposes. As a result, compared to state-of-the-art PEMFC stacks, Chinese stacks now fall short in three aspects: small per-unit capacity, low power density, and a lack of sufficient life testing.

In terms of fuel cell vehicle development, as opposed to research and development on fuel cells alone, China only began its R&D efforts about five years ago. By October 2002, a total of seven Chinese FCVs had been demonstrated. The first, a golf cart, was demonstrated by Tsinghua University in December 1999.[9] It has a 5 kW FC built by a private Chinese company called Beijing Fuyuan New Technology Development Corporation using an imported Nafion membrane.[10] The most recent demonstration FCV in China, which was unveiled in October 2001, is a four-door FC/battery hybrid sedan named Phoenix, the result of collaboration among the Shanghai Automobile Industry Corporation, Shanghai Jiaotong University and the General Motors Corporation. GM provided a 25 kW fuel cell.

Determined to catch up

In 1996, the Global Environment Facility (GEF) provided the first international assistance to China for fuel cell vehicle development. The project was an eighteen-month desktop study (including a study tour abroad) aimed at assessing the potential for commercialization of fuel cell buses in China. Last year, as part of a global program, GEF approved a five-year, $32 million project ($12 million in GEF/UNDP funding plus $20 million in Chinese government contributions) to demonstrate six fuel cell buses each in Beijing and Shanghai, as well as a hydrogen refueling station in each city.

With financial support from the W. Alton Jones Foundation, the Natural Resources Defense Council (NRDC) has worked over the last three years with various Chinese partners, including the Shanghai Economic Commission, Tongji University, the Energy Research Institute and the South-North Institute for Sustainable Development, to raise awareness in China regarding the challenges and opportunities of commercializing FCV in China. Activities include policy studies, conferences and seminars; sending Chinese experts to the U.S. for in-depth research; and a public education TV program on FCVs. NRDC has also worked with the Taiwan Institute for Economic Research to facilitate collaboration between the cities of Shanghai and Taipei on fuel cell scooter development, resulting in increased contacts and exchanges between the two cities.

This international assistance has helped center the Chinese government's attention on fuel cell vehicle development, as opposed to its previous focus on fuel cells only. In the current five-year planning period, the government has greatly stepped up its own R&D efforts with a view to developing China's own FCV technologies. Fuel cell and electric vehicles are included as one of the seven special projects under China's High Technology Development Program - often known as the 863 Program because it began in March 1986. The EV/FCV component under the 863 Program included grants of 800 million RMB ($100 million US) from the central government, which are matched by local government inputs. The program covers four areas: policy, regulations and standards; EV/FCV testing facilities and bases; complete FC car and bus assembly; and key common technologies such as battery, DC/DC converter, integrated control

[9] Ibid.
[10] GEF, op cit.

system for multiple power sources, and FC and electric engines.

A high-profile target of the EV/FCV component under the 863 Program is the development of three prototype fuel cell cars and two FC buses by 2005. Shanghai Tongji University is leading the fuel cell car project and Tsinghua University in Beijing is leading the bus project. Cars must meet the following minimum requirements: a fuel cell stack net output of 50 kW; zero tailpipe emissions; an acceleration time from 0 to100 km/hr of no more than 20 seconds; a maximum speed of at least 120 km/hr; the ability to climb a slope of at least 20 percent; a refueling range of at least 200 km; and fuel economy equivalent or better to that of a comparable gasoline car.

For buses, the minimum standards are: a fuel cell stack net output of about 150 kW; near-zero tailpipe emissions; an acceleration time from 0 to 50 km/hr of no more than 40 seconds; a maximum speed of at least 80 km/hr; the ability to climb a slope of at least 20 percent; a refueling range of at least 200 km; and fuel economy equivalent or better than that of a comparable gasoline car.

Four Chinese FC technology companies have emerged over the past few years, including the Dalian Sunrise Power Company, the Beijing Fuyuan Century Fuel Cell Power, Ltd., the Beijing Green Power Company, and the Shanghai Shen-Li High Tech Co. Ltd. The Dalian Power Company is backed by the Dalian Institute of Chemical Physics, while Green Power has teamed up with Tsinghua University. Beijing Fuyuan is a private company, and Shanghai Shen-Li collaborates with the Shanghai Institute of Organic Chemistry. All four of these companies are involved in the 863 Program's FCV projects.

In addition to the 863 R&D Program, the 973 Program, a national basic science research program, is also supporting fuel cell research during the current five-year period. One project of the 973 Program, which is budgeted at 30 million RMB ($3.75 million), is researching the mechanisms related to new hydrogen absorption materials, new fuel cell catalysts, and fuel cell membrane material.

Latest Developments

The second phase of the FCV project under the 863 Program is expected to commence in the summer of 2003. Like the earlier grants, new funding for the second phase (about 150 million RMB) will go toward promoting the development of fuel cell cars and buses. The majority of the funding will be divided among FC engine developers Shanghai Shen-Li and Dalian Sunrise Power, along with Tongji University and Tsinghua University.

Under the new funding, Shen-Li and Dalian Sunrise will develop hydrogen-based engine prototypes for vehicles to be developed and assembled by Tsinghua University and the Shanghai FCV Powertrain Co. Ltd., which is affiliated with Tongji. Shanghai FCV Powertrain Co. is expected to produce 5-7 prototype FC passenger sedans in 2003-04 using engines of either 30 kW or 40 kW capacities. Tsinghua is expected to use 80kW engines to develop prototype buses. Powertrain and Tsinghua will develop EV/FCV testing facilities, complete FC car and bus assemblies, DC/Dc converters, motor and battery testing, and vehicle structural analyses. Four smaller-scale manufacturing companies will also receive grants to produce other required parts. China hopes that these efforts will lead to demonstration of FC cars in 2005 and FC buses in 2008.

To achieve FCV commercialization, China is also studying the development of an appropriate hydrogen infrastructure system. Some scientists admit that many crucial issues remain to be closely examined and tackled. Key among these issues is hydrogen storage, although transportation and refueling issues, engine reliability and durability, and motor drive techniques are also critical. Many in China feel that the production and supply of hydrogen fuel will not be as difficult an issue because of the country's vast and flexible fuel sources. In Shanghai alone, four chemical companies have been producing enough hydrogen as an unneeded industrial byproduct to meet at least the near-term consumer needs of Shanghai and its environs.

The 863 Program has not focused on the development of fuel cell two-wheelers. Despite the lack of central government support, there have been some efforts to promote awareness that fuel cell scooters are an environmentally sound solution to the transportation need of China's emerging urbanized middle class. In February 2003, Canada's Palcan Fuel Cells Ltd. signed an agreement with four Shanghai companies for the assembly of several prototype fuel cell two-wheelers. The agreement calls for Palcan to supply five fuel cell stacks of 200W and 1kW capacities, and for the Chinese partners to develop five two-wheelers, including e-bikes, mopeds and handicapped wheelchairs.

Some Suggestions

The major research and development programs described above clearly reflect the government's determination to develop China's own FCV technologies. Will these R&D efforts be enough to help China catch up to the frontrunners in FCV development? While China is speeding up, so are the developed countries and multinational automakers, many of which have already reached the FCV pre-commercialization stage. With a large pool of fuel cell scientists, and strong engineering and manufacturing capabilities compared to most other developing countries, China possesses the necessary conditions to make the leap to becoming a center of excellence for FCV development and commercialization. The key issue is choosing the right approach.

We believe that while intensified R&D efforts will certainly move China forward in the FCV field, it may be too late to concentrate on R&D alone. China will not be able to immediately invest as much money as developed countries have poured into FCV R&D over the last several decades, and technological advancement does not come overnight. China's current R&D efforts should constitute only one dimension of an overall national strategy that aims to strengthen the Chinese auto industry's position in the new FC technology age, and to commercialize affordable and durable FCVs for Chinese citizens. Other key elements of China's strategy should be the development of financial incentive policies for manufacturers and consumers; establishment of codes and standards; public awareness and education programs; and national, regional and international cooperative efforts. We focus here on government incentive policies only.

First, the development and commercialization of FCVs cannot rely only on government funding (including that of local authorities) and governmental administrative arrangements. The participation and initiative of the automobile, energy and chemical industries are essential, and these industries must be able to sense enough future profit in the FCV market to choose to invest now. Potential profits cannot be too distant or the economics of committing present resources will not work for profit-seeking companies. Since FCVs will bring about fundamental changes in the current hydrocarbon-based energy system, and since its advantages extend beyond the purely economic, FCVs will not automatically appeal to private enterprise. Therefore, the government needs to develop incentive policies early on to motivate enterprises to join in R&D and demonstration efforts. Incentive policies might include tax breaks and subsidies for businesses developing and commercially demonstrating FCVs, a sizable and profitable government procurement plan for FCVs with open bidding, and rebates for consumers who buy FCVs. Such incentives will not have a significant impact on current government budgets, yet can mobilize the needed initiatives from the private/industrial sector. The key is not to wait until the research begins to bear fruit to start considering next steps.

Second, commercial demonstration is indispensable for FCV market development and requires the government's strong leadership. Leadership, however, should not be interpreted as the government running the show. Auto companies should take center stage, as they have both the engineering management know-how and the after-sales service capabilities needed for step-by-step commercial demonstrations of FCV fleets. Research institutions, universities and fuel cell technology companies are not well suited to lead commercial demonstrations. Governmental leadership should take the form of devising policy incentives and helping create demand for FCV products, such as government procurement and official use of FCVs at special events (i.e. Olympics 2008, World Expo 2010).

Third, R&D and technology imports are not the only ways to acquire new technology. China can also obtain FCV technologies through venture capital investment in foreign technology companies. Since FCV technologies are not yet fully developed and FCVs hold a huge market potential, China has an opportunity to spend relatively little money now in order to own a share of FCV technology, which should greatly expand in the near future. In the context of globalization, the line between foreign and indigenous technologies and products is becoming more and more blurred, while the rights to the technology and the related markets gain increasing importance. The complicated and multi-layered partnerships formed among the world's leading automakers and technology companies prove the worth of this approach. The government should encourage and assist Chinese companies to reach out in this manner by offering them special loans and credit lines.

Finally, government incentives should be directed toward both the big and the small. That is, China should broaden its focus beyond the automobile (the primary focus of most developed countries) to include fuel cell buses and scooters. As the world's most populous country, China boasts the greatest number of public buses in the world –over 226,000 in 2000 --[11] an obvious reason to give buses priority. In addition to the economic, social and environmental merits of public transportation, FCB commercialization should be easier to realize than that of private cars because buses run on fixed routes, simplifying the refueling process. FC scooters, on the other hand, require a small FC stack capacity, making their production and manufacture less technically challenging in many respects than a fuel cell car or bus. Its small size also reduces the FC scooter's total cost. Although some Chinese urban planners favor banning all two wheelers in congested urban centers out of concerns for traffic management and passenger safety, we believe that fuel cell scooters should not be grouped for policy purposes with polluting, noisy and energy-inefficient mopeds. A scooter, by Chinese official definition, should have a maximum speed of no higher than 24 km per hour, suitable to run in China's numerous bicycle lanes. With no emissions and low noise, FC scooters should create no undesired impact on a city's traffic. Considering the high population density of Chinese cities, FC scooters can be a good supplementary means of transportation for the majority of urban residents.

In conclusion, hydrogen FCV technology holds great promise for China in terms of energy security, environmental quality and industrial competitiveness. China has already launched a massive FCV research and develop program designed to accelerate FCV commercialization. To help achieve its goals, China can leverage these impressive efforts through increased international cooperation and a targeted program of government incentives.

[11] Communication with China Energy Research Institute (2002)