FUEL CELL TODAY

Opening doors to fuel cell commercialisation

Fuel Cells in China –
A Survey of current Developments

Stefan Geiger, Fuel Cell Today – 15 October 2003

China represents one of the largest potential markets for fuel cells in the world. It is the world's second largest energy consuming country and the third largest energy producing country. This survey is an extended update to our Chinese fuel cell industry report published in July 2002.

Fig.01: Traffic and pollution in China

The reasons why China has a vast potential for using fuel cells in the future are manifold. Since the opening of Chinese markets in the 1990s, rising private wealth amongst the population has resulted in an increased demand for cheap electricity and private and public transport. Since the pollution from a growing number of vehicles creates smog in many Chinese cities, the pressure to develop clean vehicle technologies is mounting. In this respect, China is in a similar position as many other newly industrialised countries. Furthermore, China's oil reserves are limited. Until 1993, the country was a net crude oil exporter but since then oil imports have increased sharply to over 75 million tons in 2000.

Although the country's efforts in developing fuel cell technology seem far behind the progress made in neighbouring countries such as Japan and Korea, China's fuel cell research activities actually began almost 50 years ago. The **Dalian Institute of Chemical Physics** started working on asbestos membrane alkaline fuel cells for space applications in the 1950s. But not until the 1990s did other research bodies and universities, such as the **Changchun Institute of Applied Chemistry**, finally join in efforts to develop modern fuel cells.

Today, China hosts more than 60 institutions and companies, employing around 350 people working on the technology. As shown in the figure below, most of these organisations are still very much research orientated.

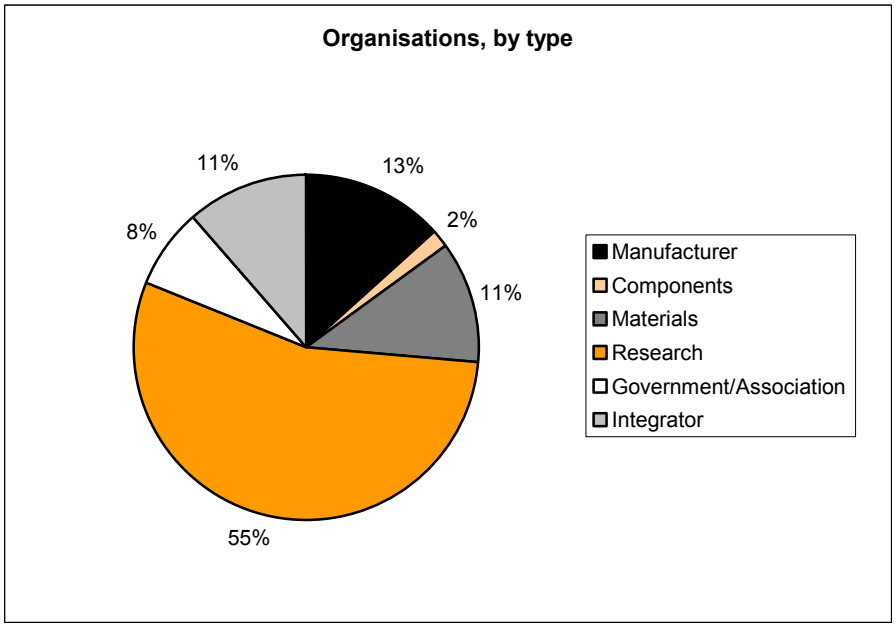

Fig.02: Chinese fuel cell organisations, by type.

So far, the country hasn't seen much private investment in this sector. Up to now, only a handful of private Chinese companies are working on the issue. However, China has seen vast investments from major car and bicycle manufacturers, some of which are already working with local research institutions on fuel cell applications.

As expected, most of the organisations involved in developing and manufacturing prototypes and products are situated in the east of the country, home of most of China's industry. Particularly the Provinces of Beijing and Shanghai count for 60% of all organisations working on fuel cells as indicated in the graph below.

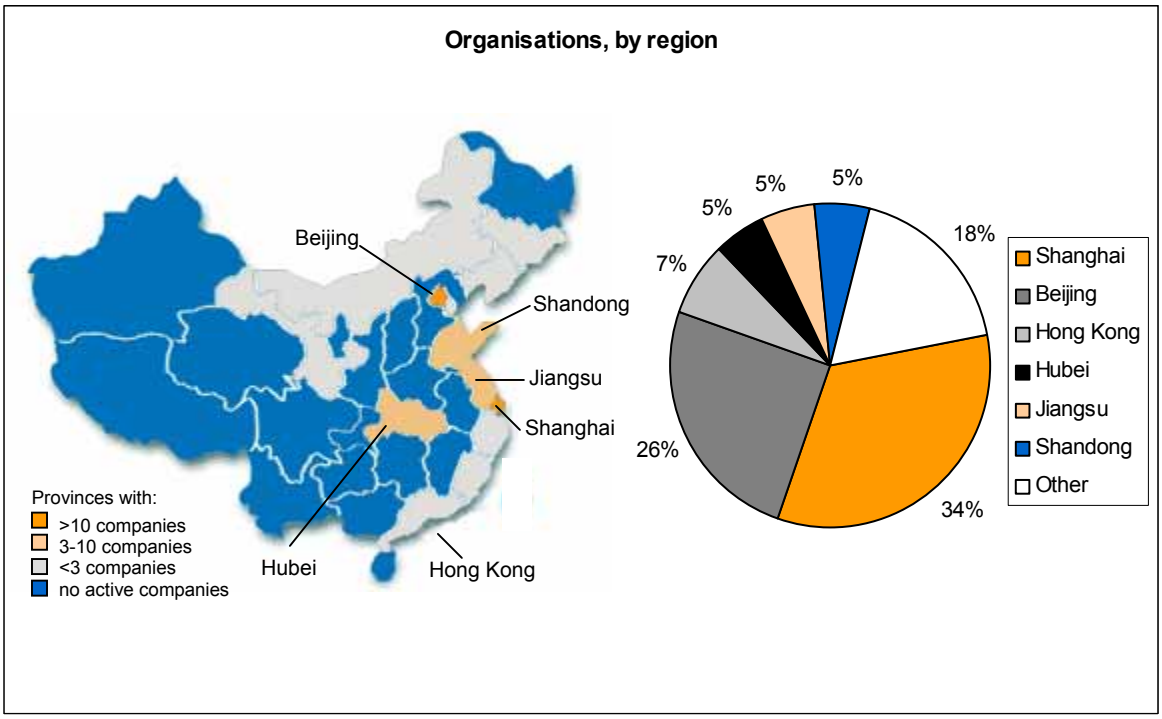

Fig.03: Location of Chinese fuel cell organisations

Applications

At present, transportation is considered to be the most important initial market for fuel cells in China, as the following figure indicates. The market for replacing batteries in electric bicycles is expected to be the earliest market by some, with buses and cars following on.

Electric bicycles are a huge business in China. There are around 400 manufacturers, producing about 2.5 million electric bicycles. This is a sharp rise from the 15,000 units in 1997. This dramatic growth is largely due to legislation banning gasoline fuelled scooters in several major Chinese cities, including Beijing and Shanghai. If fuel cell bikes and scooters can reach price targets, this could be a vast market.

Although some Chinese companies have also started working on small and large stationary fuel cells over recent years, such as the **Dalian Institute of Chemical Physics** (DICP), the first commercial fuel cell power unit to be operated in the country was a 200kW PAFC UTC Fuel Cells, installed in late 2001 at a pig farm in southern China.

On the other hand, the development of portable fuel cells has attracted some

conventional battery manufacturers, such as **Fujian Nanping Nanfu Battery** and **BYD Battery** which are doing basic research in this field.

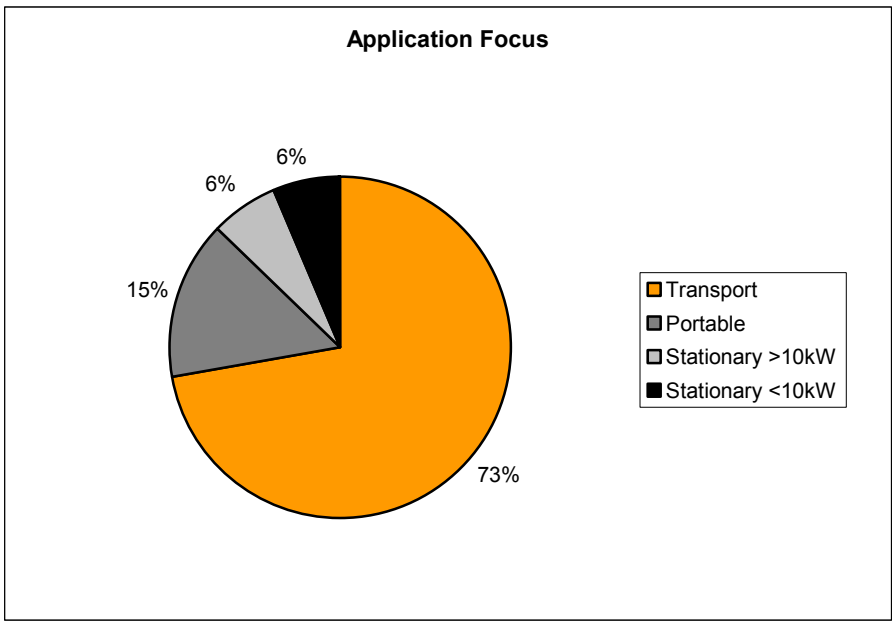

Fig.04: Chinese fuel cell organisations, by focus on application

Technology

Not surprisingly, since most efforts are concentrating on transport applications, the favourite technology amongst Chinese organisations in this field is the **proton exchange membrane fuel cell (PEM)**; a handful of organisations are also working on **hydrogen storage** (mainly metal hydride) and **infrastructure technologies**.

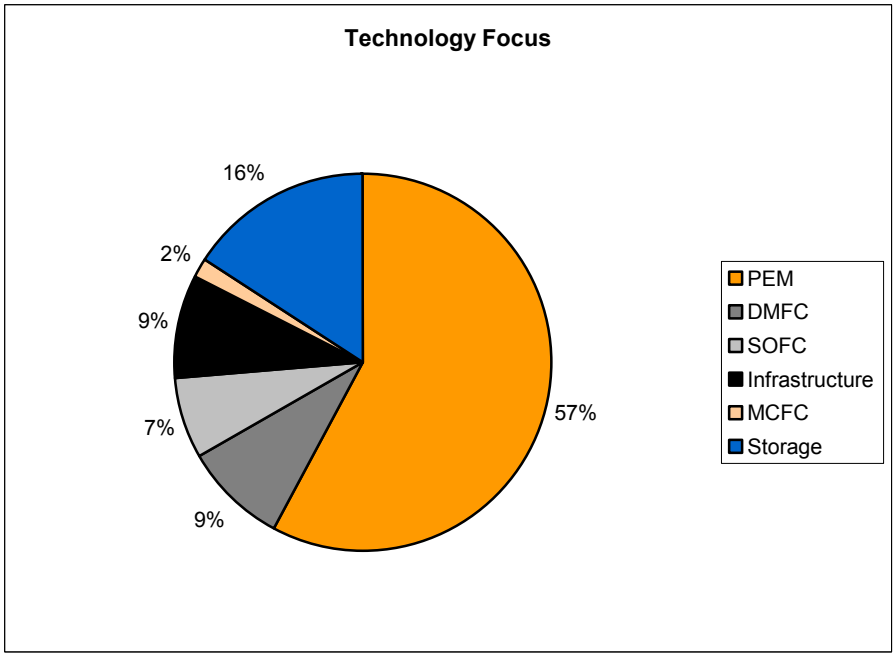

Fig.05: Chinese fuel cell organisations, by focus on used technology

Government Activities and Funding

The Chinese government started to support electric vehicle R&D in the early 1990s, although, until 2000, the focus was mainly on battery technology and electric motors. In the absence of private commercial companies, most of the grantees were universities. Since about 1999, the government has extended the electric vehicle R&D investment towards fuel cell technology as well.

However, compared to government funding efforts in the USA, Canada, Japan or Europe, the spending on fuel cells in China is generally lower but still significant. Furthermore, the money which is spend is not concentrated on the strengths of the Chinese fuel cell industry, but thinly spread on many organisations and over many technologies.

There are two major state technology programmes related to fuel cells and hydrogen research in China and some initiatives and projects, some partly-funded by the government:

The **863 programme** (named after the start date in March 1986) aims to promote the development of information, biological, agricultural, material, environment and energy technologies. During the 10th five-year plan (2001-2005) China's **Ministry of Science and Technology** (MOST) approved a 880 million Yuan (US$106 million) R&D programme to develop advanced hybrid-electric drive and fuel cell vehicles. It is expected, that private companies invest will another US$ 200-300 million over the next 5 years.

In contrast to previous programmes, this programme is focused on the commercialisation of fuel cells and on supporting the Chinese auto industry, In order to do so, the government is spending most of the money on vehicles (mostly buses rather than cars) and hydrogen production and storage. Surprisingly, there is no focus on the development of fuel cell two-wheelers. Furthermore, a small amount of the budget will be spend on SOFC and MCFC, aiming to establish two power generation plants, a 50kW MCFC and a 5kW SOFC by 2005.

The major aim of the project is to develop three prototype 50kW PEM fuel cell cars and two large 150kW fuel cell buses by 2005. The majority of the funding will be divided among the fuel cell engine developers **Shanghai Shen-Li High Tech**,

Dalian Sunrise Power and **Dalian Institute of Chemical Physics** (DICP), along with **Tongji University** and **Tsinghua University**.

Under the funding, Shen-Li High Tech and Dalian Sunrise will develop hydrogen-based engine prototypes for vehicles to be assembled by Tsinghua University and the **Shanghai Fuel Cell Vehicle Powertrain Company**. These demonstration units are seen as a first step towards China's eager plans to use 100 fuel cell buses during the 2008 Olympic Games in Beijing.

Other organisations which will benefit from MOST's funding include the Automotive Electric Institute of the **Jiaotong University**, the **China Automotive Technology and Research Centre** (CATARC), **Beijing Fuyuan Century Fuel Cell Power** and the **Beijing LN Green Power Company**.

The **973 programme** (named after the start date in March 1997) is another programme funded by the Ministry of Science and Technology (MOST), focusing on more basic research. The government is spending around 30 million Yuan (US$ 3.75 million) on the research of hydrogen storage materials, fuel cell membranes and catalysts. One of the main grantees in this sector is the **Hong Kong University** (HKUST) which is working on carbon nano materials as a hydrogen storage solution.

Additionally, China has just recently signed multinational agreement with the **Environmental Protection Agency** (EPA) in the USA and the **Italian National Board for New Technology, Energy and Environment** to work together on using hydrogen as a new clean energy source and fuel cell technology

China's two main cities, Beijing and Shanghai have also been selected by the **Global Environment Facility** (GEF), a unit of the **United Nations Development Programme** (UNDP) for the **Fuel Cell Bus Demonstration Project**. The GEF is funding a fuel cell bus project in developing and newly industrialised countries, such as Brazil, China, Egypt, India and Mexico. Under this project, which started in 1996 with the planning process and will see the bus demonstrations during 2004-07, the GEF will sponsor the deployment of six fuel cell buses and one hydrogen filling station each to both Beijing and Shanghai. The project is funded with US$ 12 million from the GEF, US$ 10 million from Chinese government, US$ 5 million each from the

cities of Beijing and Shanghai and US$ 4 million from private companies. It is planed to drive 1.6 million kilometres during the 3-year demonstration trials.

In addition to the GEF hydrogen station, **Shanghai** is working on its own **hydrogen infrastructure project**. The city will host the World Expo in 2010 and is trying to deploy its own clean energy and fuel cell buses for the event. The supply of hydrogen as a fuel in Shanghai will not be as difficult as in many other cities, mainly due to the region's vast and flexible fuel sources. In Shanghai alone, four chemical companies have been producing enough hydrogen as an industrial by-product to meet at least the near-term consumer needs of Shanghai.

Apart from these activities, there are other foundations and organisations involved in funding environmentally friendly ways of producing energy in China. **The Chinese Academy of Science** (CAS) announced in January 2002 that it intends to make China globally competitive in the field of hydrogen technology. It plans to invest up to 100 million Yuan (US$12 million) in PEMFC technology over a three-year period. Most of the money will probably go to the Dalian Institute of Chemical Physics.

In 1999, The US based **David and Lucile Packard Foundation** and the **Energy Foundation** launched the **China Sustainable Energy Programme** (CSEP), which funds Chinese non-government organisations and research institutes working on energy efficiency and renewable energy policies with US$ 5 million per year. The programme is also supported by the Lawrence Berkeley National Laboratory (LBNL).

The **National Natural Science Foundation of China** (NSFC) is an organisation directly affiliated to the State Council for the management of the National Natural Science Fund. The NSFC supports basic research and has sponsored hydrogen storage projects at the **University of Science and Technology of China (USTC)** and various institutes at the **Chinese Academy of Science (CAS)**.

The US-American **Natural Resources Defense Council** (NRDC), with the support of the **W.Alton Jones Foundation** has worked over the last three years with yhe Shanghai Economic Commision, Tongji University, the Energy Research Institute and the South-North Institute to raise awareness in China regarding the commercialisation of fuel cell vehicles. Furthermore, the NRDC has worked with the Taiwan Institute for Economic Research to facilitate collaboration between Canadian

Palcan Fuel Cells of Vancouver, the cities of Shanghai and Taipei on fuel cell scooter development.

The Department of Resources Conservation and Comprehensive Utilisation (DRCC), part of the **State Economic and Trade Commission** (SETC) of the People's Republic of China is responsible for energy savings efforts, energy efficiency, renewable energy and the promotion of fuel cell technology development in China.

Key Players

The **Beijing Fuyuan Fuel Cell Group** consists of two companies: the Beijing Fuyuan Century Fuel Cell Power Limited Corporation and the Beijing Fuyuan Pioneer New Energy Material Limited Corporation. **Bejing Fuyuan Century Fuel Cell Power** is developing PEMFC technology. It has developed stacks ranging in size from 3W to 30kW. Prototypes include a 3W system for mobile phones, a 30W system for laptops and a 300W system for scooters or electric bicycles. In 1998 the company developed the first fuel cell powered vehicle in China in conjunction with the Automotive Engineering Department of **Tsinghua University**, installing a 5kW stack into a prototype golf cart. One year later, a sedan car was developed with Tsinghua University. More recently, Beijing Fuyuan has built and tested 40kW PEM fuel cells for cars and 150kW units for buses.

Furthermore, the company has developed a 200W PEM system which it has shipped to the Japanese company QM Soft, which plans to sell 50 of the portable units per month (price about US$ 3,500).

Sister company **Beijing Fuyuan Pioneer New Energy Material** specialises in the R&D and production of PEMFC components, including carbon, platinum catalysts, composite, metal bi-polar plates and PEMFC membranes.

Beijing Jinfeng Aerospace S&T Developments Company is the country's largest producer of hydrogen storing metals and one of 13 manufacturers which have a combined production capacity of 7,000 tons/year. The company is working on possible uses of hydrogen for transport applications.

The **Beijing LN Green Power Company** (Beijing LN Power Sources), established as the LN Research Institute in 1998, is attempting to transfer their experience in electric vehicles to fuel cells.

In 2001, together with the Electric Vehicle R&D Centre of the **Beijing Institute of Technology** (part of the Chinese Academy of Science), LN Green Power presented a PEM fuel cell powered taxi with a range of 150km and a top speed of around 75km/h. In the same year, a PEM fuel cell car (range 50km, top speed 24km/h) was showcased, which was developed with the **Tsinghua University** and the Beijing Institute of Technology. Furthermore, a small 12-seater fuel cell bus was presented at the same time.

Fig.06: PEM fuel cell car. Source: Tsinghua University

BYD Battery Co, a manufacturer of rechargeable batteries, has reported that a number of its 200 strong R&D team are working on fuel cells, but no details are forthcoming at present. The company is based in southern China, near Shenzhen.

Cathay Advanced Materials is a manufacturer and supplier of high purity rare earth materials, metal oxide materials, alloys and yttrium zirconium compounds.

The **Changchun Institute of Applied Chemistry** (part of the Chinese Academy of Science) is working on nickel based alloys for storing hydrogen and on molten carbonate salts. Furthermore, the institute has been working on 1-100W direct methanol fuel cells for portable applications.

The **China Association for Hydrogen Energy** (CAHE) aims to promote hydrogen as a clean fuel for fuel cells and various other applications. The association is organising the HYFORUM event, one of the largest hydrogen and fuel cell related conference in China.

Fig.07: 75kW PEM system. Source: DICP

Dalian Institute of Chemical Physics (DICP) has been carrying out fuel cell R&D for more than 50 years. During the 1960s to 1970s, Alkaline Fuel Cells (500-600W) were successfully developed. In the 1980s DICP developed an Alkaline free-electrolyte flow H_2-O_2 fuel cell and a large capacity energy storage fuel cell.

Other research areas have included the development of thin metal bipolar plates that are easy to manufacture, and the development of MEA manufacturing processes. There has also been some work on direct methanol fuel cells (DMFC) and catalyst development.

Fig.08: 30kW PEM fuel cell bus. Source: DICP

In the last decade DICP has been developing Proton Exchange Membrane Fuel Cells, Molten Carbonate Fuel Cells and Solid Oxide Fuel Cells. The centre employs more than 70 researchers and engineers in three different R&D groups working on stacks in a range between 1-75kW for small and large stationary, transport and portable applications. DICP has demonstrated various cars and small and large fuel cell buses in 2001-03, most of which had a 30kW PEM stack. In spring 2003, the institute supplied its new 75kW PEM stack to **Tsinghua University** which integrated the unit in a bus. Furthermore, DICP has established a co-operation with **Samsung Electronics** to set up a joint research laboratory for the work on direct methanol fuel cells. In August 2003, DICP has signed a contract with **Toyota** to jointly develop clean energy vehicles, including the use of fuel cells.

In 2001 DICP established **Dalian Sunrise Power Co. Ltd** with a number of other Chinese organisations to commercialise its fuel cell technology. Work carried out by this company includes the development of a fuel cell bicyle powered by a 200W PEMFC in conjunction with DICP and Shanghai Qianhe Bicycle Plant. This was exhibited at the 2001 Shanghai Industry Exposition.

The **Fujian Nanping Nanfu Battery Company** (Nanfu Battery) is the leading battery manufacturer in China. In 2002, the company has signed an agreement with the Dalian Institute of Chemical Physics (DICP) to develop portable direct methanol fuel cells. Nanfu will support these effort with US$ 1.2 million over 4 years.

The **General Research Institute for Non-Ferrous Metals** (GRINM), is doing research related to hydrogen storage including high-pressure storage and sensors. The general Research Institute for Non-Ferrous Metals is developing hydrogen storage materials using rare earths, titanium, magnesium and nano-hydrogen. They also produce and sell metal hydrides, and hydrogen storage containers for fuel cells for mobile phones, bicycles and motor scooters.

The Centre for Hydrate & Natural Gas Research at the **Guangzhou Institute of Energy Conversion** (GIEC) is working on researching renewable energy technologies. GIEC has received funding from the government's 973 programme in order to develop energy and gas storage systems and a small stationary methane fuel cell.

Inner Mongolian **HEFA Rare Earth Science & Technology Development Company** is a Chinese-Canadian manufacturer and distributor of rare earth oxide, hydrogen storage powder, and nickel-hydrogen materials. The company works closely with the **Nankai University** on hydrogen storage technology project. Early developments have resulted in a new magnesium based hydrogen storage alloy which has higher hydrogen storage capabilities than alloys prepared by metal melting methods.

The Department of Materials Science and Engineering at the **Huazhong University** is working on hydrogen storage alloys and the development of new proton exchange membranes.

Nanjing BINKI Industry Company manufactures and supplies perfluorinated ionomer membranes and perfluorinated powder/resin for PEM and DMFC. The company claims that its material has some advantages over Nafion, including isotropy, high crystallinity, and resistance to oxygenation.

The **NewEco Developing Centre** is a renewable business and ecological economy organisation based in Beijing, China. NewEco provides research & development, system design, consulting services in the field of renewable energy, including solar, wind, fuel cell and biomass.

The Canadian fuel cell manufacturer **Palcan Fuel Cells** has signed strategic fuel cell and hydrogen research agreements with various Chinese organisations. This year, Palcan has supplied a 300W PEM stack to bike manufacturer **Shanghai Giant & Phoenix Bicycle** to power a fuel cell scooter and a 1.5kW stack to the **Shanghai Wheelchair Factory** to power a wheelchair.

Furthermore, a 5kW stack will be supplied to the steel, ship and power generator manufacturer **China Shipbuilding Industry Corporation** (CSIC 711), which will integrate the unit into a boat.

The **Pan Asia Technical Automotive Centre** (PATAC) is a US$50 million, 50-50 joint venture between **General Motors China** and the **Shanghai Auto Industry Corporation** (SAIC). It provides automotive engineering services including design, development, testing and validation of components and vehicles for automotive companies in China and the Asia Pacific region. In 2000, PATAC presented the fuel cell vehicle "Phoenix", a 2.5t General Motors Buick minivan, powered by a 35kW PEM fuel cell with a top speed of around 110km/h.

The **Shandong Blue-Sky New Energy Company** is developing zinc-air fuel cells, mainly to power small electric vehicles, such as bicycles and scooters.

Shandong University is working on storing liquid hydrogen and bio-hydrogen. Furthermore, the university is researching ways of reforming and producing hydrogen from ethanol, organic solvents, fodder, methane or by using photosynthetic bacteria.

The **Shanghai Auto Industry Corporation** (SAIC) is China's largest car manufacturer, producing almost half of the vehicles sold in the country. Apart from its joint fuel cell activities in the PATAC, SAIC is also working on its own developments. In 2003, the company presented its first fuel cell car prototype, the "Chao Yue 1". The car is based on VW's old Santana sedan and can reach a top speed of 110km/h. SAIC has invested US$ 4.6 million in its fuel cell research campaign and has received another US$ 10 million from the Chinese government to continue its efforts throughout 2004. The company plans to bring out a small demonstration fleet in 2005.

Fig.09: VW Santana, which is the platform for SAIC's fuel cell vehicle "Chao Yue 1". Source: SAIC.

In 2001, moped and bicycle manufacturer **Shanghai Forever Company** (Shanghai Forever Bicycle) has signed an agreement with Palcan Fuel Cells for the manufacturing and integration of a portable fuel cell system into Forever's popular electric bicycle and low speed electric motor scooters. Furthermore, the two companies have agreed to jointly development and demonstrate further generations of fuel cell powered vehicles.

The **Shanghai Institute of Ceramics**, part of the CAS, is researching and developing materials for planar SOFC stacks.

The **Shanghai Institute of Organic Chemistry** (SIOC), part of CAS, is a leading research institution in organic chemistry in China with significant contributions to the development of national science, economy and defense. As a leader in PEM research, SIOC has made prominent advances in partial fluorine PEM. SIOC is the primary shareholder of **Shanghai TL Chemical Company** which was established in 2002 to develop and commercialise PEM and MEA technologies.

The Institute of fuel cells at the **Shanghai Jiao Tong University** is working on small stationary (<10kW) PEM and MCFC and electrolysers. The university has received a US$1.8 million funding from the Chinese government to support these efforts. Future work will include the development of 3-5kW residential PEM units, 1kW SOFC units and 10-50kW molten carbonate fuel cells.


Fig.10: 500W PEM bicycle. Source: Shen-Li

Founded in 1998, **Shanghai Shen-Li High Tech Co Ltd** (God's Power High Tech) is developing PEM fuel cells for a whole array of applications, from portable power to mini-buses. Currently employing around fifty people, it has developed a series of prototypes, ranging in output from 10W to 50kW. Future projects include the development of fuel cells in the 1-10W range to power mobile phones and other devices. Shen-Li has successfully demonstrated a 2.5kW PEM scooter, a 40kW car, a 500W bicycle (jointly developed with **Su-Zhou Machinery**)and a 4.8kW small sight-seeing vehicle with plans for a 30-80kW PEM minibus.

The company has been supported by the government's 863 programme to develop PEM membranes and a 30kW stationary power unit and has also received funding from the local government in Shanghai to develop a 5kW small stationary unit. Shen-Li has a close working relationship with the **Shanghai Institute of Organic Chemistry**.

Shanghai Yung-Qiang Technology, a subsidiary owned by Shanghai Marine Diesel Engine Research Institute is working with **Palcan Fuel Cells** on manufacturing and developing various hydrogen and air fuel subsystem components for Palcan fuel cells. Yung-Qiang will invest around 800,000 Yuan (US$ 98,000) on a new lightweight container development for Palcan's proprietary low pressure metal hydride storage material.

The **South-North Institute for Sustainable Development** (SNISD) is a Chinese non-profit NGO based in Beijing. It works on legislation, regulations and policy of environmental protection and sustainable development, and promotes the use of

renewable energy, especially in the Asia-Pacific region. Its fuel cell related work includes an ongoing project which aims to develop a ten year strategy for the development and commercialisation of fuel cell vehicles in Shanghai.

Fig.11: Small Antelope Electric Bike which the company plans to equip with fuel cells. Source: Suzhou Small Antelope Company.

Electric bike producer **Suzhou Small Antelope Electric Bicycle Company**, part of the Suzhou Chuangyuan Group has signed an agreement in 2002 with Palcan Fuel Cells for the development of a fuel cell powered bicycle based on the Small Antelope electric bike and incorporating Palcan's PalPac portable fuel cell system. Another joint venture with **Beijing Fuyuan Century Fuel Cell Power** aims to develop 100-5,000W fuel cells for scooters and motorbikes.

The Centre of Automotive Engineering at the **Tongji University** is working on the promotion of fuel cell and hybrid vehicles, a project funded by the China Sustainable Energy Programme. The company's research centre also has experience in PEM vehicle development and created the spin-off company **Shanghai Fuel Cell Vehicle Powertrain,** which is one of the main grantees of the government's 863 programme. The company is expected to produce 5-7 prototype fuel cell passenger cars within the next few years, using engines of either 30kW or 40kW capacity.

Tsinghua University is in charge of the National Key Fundamental Projects: "Fundamental Research for Hydrogen Production, Storage and Transportation in Large Scale and Relative Fuel Cells" and "Fuel Cell Engines Used for Buses." The university is working on developing PEM fuel cells, fuel cell engines and making hydrogen from ethanol. In 1999, Tsinghua demonstrated a 5kW PEM fuel

Fig.12: PEM fuel cell bus. Source: Tsingua University

cell powered golf car, the stack developed by **Beijing Fuyuan Century Fuel Cell Power**.

Together with **Beijing LN Power Sources**, Tsinghua University has presented various vehicles in 2001, one of which was a small 12 seater bus (top speed 90km/h, range 160km). As part of the government's 863 programme, Tsinghua University is expected to use a 80kW engine to develop another prototype bus.

Zhejiang University Science Park Development Company, a spin-off of the Zhejiang University is also working with Canadian fuel cell manufacturer Palcan. The company is developing a metal hydride storage canister exchange concept which will be suitable for low wattage applications under two kilowatts.

The advanced energy materials research laboratory at the **Zhongshan University** (Sun Yat-Sen University) is conducting basic research in advanced energy materials and technologies, such as nano-materials, fuel cells, catalysts, electrochemical sensors, nano-composite materials and high performance polymer materials.

Other organisations in China which are working on the development of fuel cell and hydrogen technologies include the **Beijing Institute of Aerospace Testing, Centaurus Limited, Hyper Battery** (China Hyper Power Battery), **Institute of High Energy Physics** (IHEP), **Jiangsu University**, the Automotive Electric Institute at **Jiaotong University**, **Optegy Energy Consulting**, **Shiu Wing Steel**, **Tianjin University**, **University of Science and Technology of China** (USTC), **Voller Energy China**, **Wuhan University** and **Xiamen University.**

About the author

Stefan Geiger works for Fuel Cell Today, the global Internet portal for companies and individuals with an interest in the commercialisation of fuel cells. It is your single free source for comprehensive and authoritative fuel cell news, commentary, resources and business opportunities. To contact the author, please send an email to: stefangeiger@fuelcelltoday.com