FUEL CELL TODAY

Opening doors to fuel cell commercialisation

Fuel Cell Market Survey:
Automotive Hydrogen Infrastructure

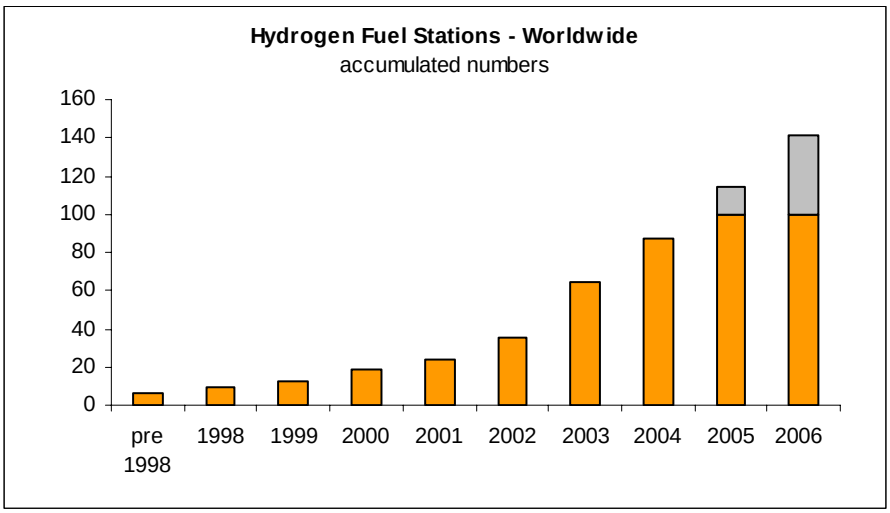
Alexandra Baker, Fuel Cell Today – 25 May 2005

Hydrogen infrastructure development is an essential part of fuel cell commercialisation presenting the famous chicken and egg question of what comes first. Currently, the number of stations is slowly increasing supported through different grants alongside the development and testing of fuel cell, and hydrogen internal combustion engine, vehicles. Although there are no fully commercial examples yet, we have seen stations opening where hydrogen pumps are integrated into the existing petroleum fuelling facilities, an important step in public acceptance of hydrogen as automotive fuel.

Since the publication of our last hydrogen infrastructure survey back in May 2004 we have seen further encouraging developments, although the same issues dominate the industry including production, storage and distribution. During the last twelve months we have seen around 30 stations opening worldwide with the majority located in the USA. There were mainly in California where **CaFCP** (California Fuel Cell Partnership) and the South Coast **AQMD** (Air Quality Management District) have a number of demonstration projects. CaFCP members have already placed more than ninety fuel cell vehicles and buses on California roads. Within two years, CaFCP anticipates that up to 300 vehicles will be operating in the state and as many as 50 fuelling stations providing a foundation for Governor Schwarzenegger's Hydrogen Highway Net according to Chris White, communications director for California Fuel Cell Partnership. AQMD is co-funding 14 hydrogen stations in Southern California supporting a fleet of 35 hydrogen electric-hybrid Toyotas.

The total number of stations have reached 100 units worldwide with another 15 expected to be completed by the end of 2005 as indicated on the chart below. In

2006 we are anticipating that another 30 to 40 stations will be opened across the globe.



Worldwide number of H2 fuelling stations. Orange bars indicate operating stations; grey bars are a forecast for 2005 and 2006.

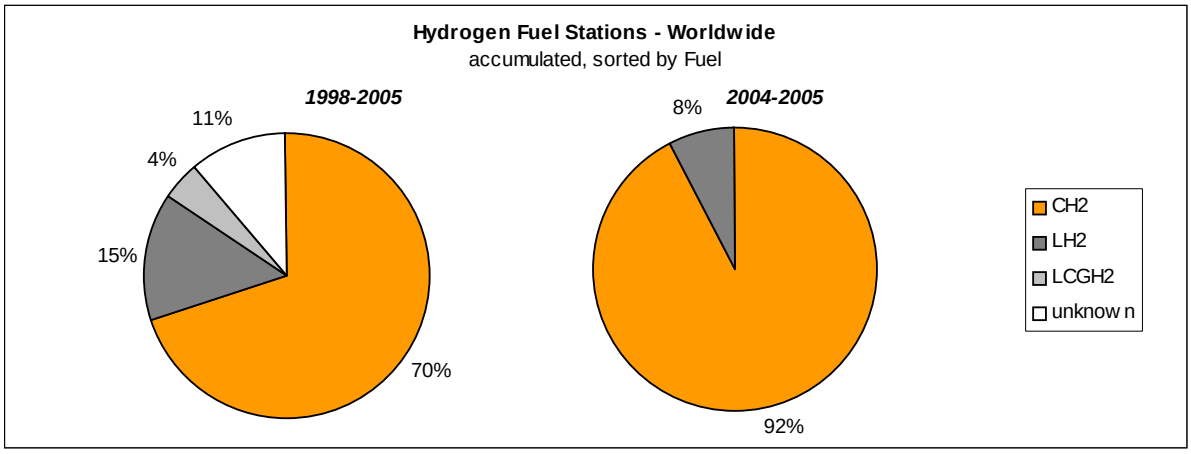
A further developing trend we have noticed is that renewable hydrogen generation is attracting further attention as more countries are trying to reduce their dependency on fossil fuels and improve air quality. There is already a good foundation based on small scale demonstrations producing hydrogen through sustainable sources that we expect to increase within the next few years.

Fuel

In terms of type of fuel dispensed at the stations we still see a clear trend towards compressed hydrogen. The left chart in the graph overleaf, indicates the share of different fuel types distributed at refuelling facilities built from 1998 to the present. The chart on the right demonstrates that the majority of the stations opened over the last two years provide compressed hydrogen.

It is also important to note that all the stations with liquid hydrogen built in 2004-2005 included in 8% in the graph overleaf will also have compressed hydrogen dispensers. The main reason for using compressed hydrogen at fuelling stations is that most new fuel cell cars and buses run on this form of fuel. Liquid hydrogen,

however, cannot yet be written off as advances in technology and refuelling will still be made before commercialisation takes place.



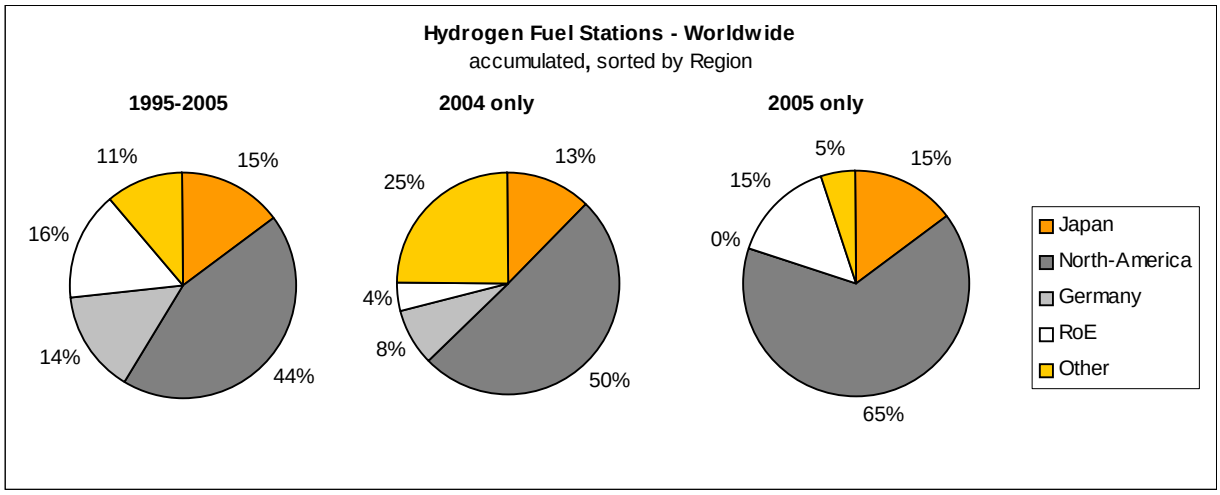
Fuel used in existing hydrogen stations. Left: All existing stations. Right: Stations built in 2004-2005. (CH2=Compressed gaseous hydrogen, LH2=Liquid hydrogen, LCGH2=Liquid to compressed gaseous hydrogen)

Hydrogen, of course, is not the only fuel option under development but we have not seen recent evidence of significant numbers of fuel cell vehicles that run on other types of fuel such as methanol or natural gas.

Region of Interest

During the last twelve months the majority of the refuelling stations were opened in North America. This is shown on the graph overleaf and is due not only to the increased activity in the USA but also demonstration projects elsewhere slowing down. For example, in Europe all the stations required for the Clean Urban Transport for Europe (**CUTE**) project are already built with no new big projects coming online yet. With regards to the 'other' category plotted on the chart in 2004 we have seen stations opening in Australia, China, Singapore and Taiwan as part of various projects. China, for example, proposed the introduction of fuel cell buses during the Olympic Games in Beijing in 2008 and the World Expo in Shanghai in 2010. However, in 2005 the low number of opened fuelling facilities was mainly attributed to the lack of anticipated activities especially the much delayed **UNDP-GEF** (United Nations Development Programme - Global Environment Facility) project which planned to provide 46 fuel cell buses to Beijing, Cairo, Mexico City, New Delhi, Sao Paulo and

Shanghai. The time line for this project is unclear and we have not seen any evidence of progress.



Hydrogen filling stations worldwide displayed by region. Left: All stations in operation. Middle: Stations built in 2004. Right: Stations built in 2005 or in construction as of May 2005.

On the other hand, high activity on the hydrogen front in the USA included contributions from the **AQMD** Hydrogen Project, **DoE** demonstrations and other smaller initiatives. California had the largest number of refuelling stations built during the last twelve months and we are expecting that it will retain the lead in the coming year.

Technology Issues

There are a lot of technological issues associated with the development of hydrogen infrastructure on a large scale including production, storage and distribution. Although the process of producing hydrogen in bulk is established for industrial applications, it is not always possible to link these production sites to supply automotive hydrogen. Transportation of hydrogen is associated with large cost, as hydrogen storage still remains a bottleneck of the process. In order to avoid such distribution problems **H2Gen, Hydrogenics** and **HyRadix** amongst others have come up with different solutions for distributed hydrogen generation.

H2Gen units, for example, are based on a known technology of steam methane reforming but on a much smaller scale than centralised large industrial production. These units are capable of producing 113 kg of hydrogen a day, which is equivalent

to a refuelling capacity for 20 cars per day. HyRadix uses autothermal reforming in its hydrogen generation units which able to produce around six times more per hour than the H2Gen system. One of the smaller HyRadix units is being trialled by California's SunLine Transit Agency to supply hydrogen for mixing with natural gas and use in its HCNG buses. Neither company is limiting themselves to the fuel cell market and both are therefore also supplying their units for other applications.

Currently, all industrial hydrogen is generated through reforming of fossil fuels or by electrolysis of water, which usually uses grid electricity generated by fossil fuels. There is a push towards generating hydrogen through sustainable methods further improving air quality and reducing dependency on oil. Renewables that can be utilised for hydrogen production include wind energy, tidal and solar power. **Hydrogen Solar** is one of the companies that specialises in hydrogen production and is working with nanotechnology to enhance the efficiency of its photoelectrochemical cell. The system, called Tandem Cell, can convert more than 8% of the energy from sunlight directly into pure hydrogen – closing in on the 10% solar-to-hydrogen conversion level quoted as the benchmark for commercially viable hydrogen production.

Regulations and Standards

Another challenge the industry is facing remains the lack of international regulations and standards for hydrogen storage, fuelling, transportation, purity, maintenance of fuelling stations, the refuelling interface and filling equipment specifications. For example, it has taken a year to approve a hydrogen filling station in Hornchurch (London) for the CUTE (Clean Urban Transport for Europe) demonstration project. This was mainly due to the resistance of local residents who were concerned about a lack of information on hydrogen safety.

There are, though, organisations across the globe which are working on the codes and standards for the industry. In North America these organisations include the Canadian Standards Agency (**CSA**), its US Partner the American National Standards Institute (**ANSI**), the American Society of Mechanical Engineers (**ASME**), the US Department of Energy (**DoE**) and Underwriters Laboratories (**UL**).

The Japanese government and delegates of the European Union are working with car manufacturers and the International Organisation for Standardisation (**ISO**) on (appropriately) standardisation of codes and standards. One of the ventures aimed at developing common international standards and regulations in this area is the **EIHP** (European Integrated Hydrogen Project). Additionally, the International Partnership for the Hydrogen Economy (**IPHE**) is working with its members on establishing internationally consistent codes and standards to ensure hydrogen safety and aid fuel commercialisation. One of the challenges in this work is to reach a consensus between Europe, Japan and the USA which are the main players in this field.

Current Major Demonstration Projects

CaFCP – California Fuel Cell Partnership

The partnership started in 1999 as a collaborative 4-year project between auto manufacturers, energy firms, fuel cell technology companies and government. The project was then extended and the second phase, which began in 2004 with funding from the DoE and private companies, will continue until 2007. The aim of the partnership is to demonstrate fuel cell powered cars and buses on public roads in California, promote practical codes and standards and to educate the general public about the advantages of such vehicles.

So far, there are a total of 65 fuel cell vehicles on the roads of California with 15 stations supplying the hydrogen. An additional 9 refuelling stations are planned to be opened by the end of 2005. By 2007, the partnership aims to have 300 vehicles in place. Major partners include **Air Products, Ballard, BP, ChevronTexaco, DaimlerChrysler, Department of Energy** (DoE), **Department of Transport** (DoT), **EPA, ExxonMobil, Ford, General Motors** (GM), **Honda, Hydrogenics, Hyundai, ISE, Methanex, Nissan, Pacific Gas & Electric, Praxair, Proton Energy, Shell Hydrogen, Toyota, US Army National Automotive Centre, UC Davis Institute of Transportation Studies, UTC Fuel Cells, Volkswagen** and **Ztek**.

CH2IP

The Compressed Hydrogen Infrastructure Program (CH2IP) aims to demonstrate the viability of hydrogen infrastructure for both transportation and power generation markets. The consortium of companies, including **BCHydroGEN** (part of BC Hydro), **BOC, BP, ChevronTexaco, Dynetek, Fuel Cells Canada, JFE, Powertech, Shell Hydrogen** and **Stuart Energy** (now **Hydrogenics**), has started three infrastructure projects in recent years. Firstly, a hydrogen filling station with 350bar pressure was developed which was, in a second step, increased to 700bar. It now supplies hydrogen for a fuel cell vehicle as part of the Vancouver Fuel Cell Vehicle Programme and other hydrogen internal combustion vehicles. The final stage is a mobile satellite CH2 station which supplies hydrogen at 250 and 700bar.

Clean Energy Partnership (CEP)

The Berlin Clean Energy Partnership is a 5-year project of the "**VES – Verkehrswirtschaftliche Energie Strategie**" (TES – Transport Energy Strategy), a German Federal Government funded organisation, which aims to develop a medium- and long-term strategy to implement an infrastructure for alternative fuels. The CEP programme consists of a consortium of companies including **Aral** (part of the BP Group), **Berlin Public Transport, BMW, DaimlerChrysler, Ford, GM/Opel, Hydro/GHW, Linde** and **Vattenfall Europe**. In November 2004 the partnership opened a filling station in Berlin capable of supplying both liquid and compressed gaseous hydrogen for up to 350 vehicles a day.

Controlled Hydrogen Fleet & Infrastructure Demonstration and Validation Project

This project is also known as the Hydrogen Learning Demonstration. The aim of the programme is to provide data that will allow DoE to focus its research and development efforts as well as helping to address safety and codes and standards issues. The US Department of Energy (DoE) will fund this 5-year programme (2004-2009) with US$ 190 million, the same amount coming from private industry. The DoE Hydrogen Programme supports the President's Hydrogen Fuel Initiative and integrates related activities in the Offices of Energy Efficiency and Renewable Energy (EERE); Fossil Energy; Nuclear Energy, Science and Technology; and Science. The Department of Transportation also supports the initiative in the areas of hydrogen

safety and codes and standards. There are four industry groups for this programme with **ChevronTexaco**, **DaimlerChrysler**, **Ford** and **General Motors** being leaders in respective groups. Other partners in the project include **Ballard, BP, California Department of General Services, City of Taylor** (Michigan)**, City of Ann Arbor** (Michigan)**, DTE Energy, Florida Department of Environmental Protection, Hyundai, NextEnergy, Progress Energy, Quantum Technologies, Sacramento Municipal Utility District, Shell, State of Maryland, Viewpoint Systems, US Army, US Marine Corps** and **UTC Fuel Cells**.

Fuel Cell Bus Club

The fuel cell bus club comprises the **CUTE** (Clean Urban Transport for Europe) project, **ECTOS** (Ecological City Transport System) and **STEP** (Sustainable Transport Energy for Perth) projects and in total runs 33 **DaimlerChrysler** Citaro fuel cell buses in 11 cities. Each city has a refuelling station which produces hydrogen through a variety of methods. The major partners in the refuelling aspects of the projects are **BP**, **Norsk Hydro** and **Shell**. In April 2004, DaimlerChrysler also delivered one Citaro fuel cell bus to China, as part of an agreement with the Canadian **BC Transport**.

Various fuel cell bus club refuelling stations

Interestingly, within the entire bus club only one station, the one in London, has experimented with liquid hydrogen. Funding to continue the CUTE project has been applied for, under the acronym **CUTE +**. STEP is due to run until the end of 2006 and ECTOS has also applied to extend the period the buses will be running.

As of April 2005 the joint CUTE, ECTOS and STEP fleet has passed the milestone of 50,000 operating hours. Reports from the projects indicate that the bus technology is working well but that the refuelling technology is not as reliable and needs further substantial R&D before commercialisation can begin.

JHFC

The Japan Hydrogen & Fuel Cell Demonstration Project (JHFC) consists of a Fuel Cell Vehicle Demonstration Study and a Demonstration Study of Hydrogen Fuelling Facilities. The programme aims to gather data on hydrogen production methods from various fuels and FCV performance in real life conditions. The project ran from 2002-2005 and is funded by the Japanese **Ministry of Economy, Trade and Industry** (METI) and supported by the **Japan Automobile Research Institute** (JARI) and the **Engineering Advancement Association of Japan**. This project is expected to continue in a second phase.

There were two fuelling stations built for the Expo 2005 Aichi Japan where fuel cell buses are being used as part of transport infrastructure for the exhibition site.

Several vehicle manufacturers, including **DaimlerChrysler, General Motors** (GM), **Hino, Honda, Mitsubishi, Nissan, Suzuki** and **Toyota** have their vehicles on public roads in the Tokyo, Chiba and Kanagawa area. There are around 50 fuel cell vehicles being operated in Japan and 10 hydrogen filling stations installed as part of this project. Hydrogen is being generated from a variety of sources including natural gas reforming, water electrolysis, naphtha, kerosene, gasoline and methanol reforming.

Participating companies include **Babcock-Hitachi, Cosmo Oil, Idemitsu Kosan, Itochu Enex, Iwatani International, Japan Air Gases** (joint-venture of Air Liquide and Osaka Sanso Kogyo), **Kurita Water Industries**, **Nippon Oil** (ENEOS), **Nippon Sanso, Nippon Steel, Sinanen, Showa Shell** and **Tokyo Gas**.

Hydrogen Highway (in British Columbia)

Hydrogen Highway is part of a wider Canadian industry initiative including the Hydrogen Village and the Vancouver Fuel Cell Vehicle projects. The plan is to have seven hydrogen fuelling stations connecting Whistler with Victoria as part of the plan for British Columbia to demonstrate green technologies during the Whistler 2010 Winter Olympic Games. In the longer term the idea is to extend this network South

towards California. The concept is to have a prototype hydrogen infrastructure in place by 2008 with the completion of the first phase scheduled for April 2007.

Fueling Technologies, Powertech Labs and **Sacre-Davey Engineering** will be responsible for fuelling facilities. Other partners in the project include **Ballard, BC Hydro, Fuel Cells Canada,** the **National Research Council Canada, Natural Resources Canada (NRCan)** and **QuestAir**. To start the project and to get some initial experience, **Ford** has delivered four fuel cell vehicles to Vancouver in 2005.

Wasserstoff-Kompetenzzentrum Berlin

The planned project now appears to be permanently stopped and therefore the CEP project is the main technology promotion programme in Berlin for fuel cells and hydrogen. The consortium included the local transport company "**Berliner Verkehrsbetriebe**" (BVG), **Linde Gas, MAN, Opel, Proton Energy** and **TOTAL Deutschland**, with funding from the European Union.

WE-NET

The Japanese WE-NET (World Energy Network) was initiated in 1993 to develop new technologies and fuels for transport applications. Funded by the **Ministry of Economy Trade and Industry** (METI), the focus during the first phase (1993-98) was on the development of a long-term concept in using hydrogen as a fuel. During the second phase (1999-2002), results were put into practical use by installing three filling stations in Japan and running various fuel cell vehicles. The project has now changed its name to "Development for Safe Utilisation and Infrastructure of Hydrogen" and the project members, including the **New Energy and Industrial Technology Development Organisation** (NEDO) and various research organisations, focus their work on codes, standards and safety issues, while using the fuelling stations which are still in operation.

Future Demonstration Projects

Some of the new demonstration projects described on the following pages are overlapping in terms of stations to be built, car manufacturers involved and funding, especially the projects in California. Governments and funding agencies, in the USA

in particular, often propose “new” projects, which essentially use funding already given to organisations during previous programmes.

AQMD Test Fleet

The Californian South Coast **Air Quality Management District** (AQMD) is funding a fleet vehicle project, which will convert 35 Toyota Prius hybrids to run on hydrogen instead of gasoline to gain real-world experience with a hydrogen fleet, compare different fuelling strategies and hydrogen production methods, as well as educate the public on this fuel. There will be five hydrogen filling stations installed as part of this project in Burbank, Ontario, Riverside, Santa Ana, and Santa Monica by the end of 2005. The AQMD is funding US$2 million toward a total project cost of more than US$4 million, with **Quantum**, the vehicle conversion company, five local cities, and possibly the US **Department of Defense** paying the balance of the cost.

California Hydrogen Highways

Probably the most ambitious efforts in creating an infrastructure are currently taking place in California. By 2010, the government would like to see around 200 filling stations, providing access to hydrogen along the state's major highways. However, it should be noted, that this highway concept is an “umbrella” project, combining other activities in the state, including the efforts of the AQMD and the California Fuel Cell Partnership. The first station on the Hydrogen Highway network was opened in October 2004 at Los Angeles International Airport.

DaimlerChrysler has already announced that it will add another 37 fuel cell vehicles on the road in North America during the programme, **Ford** aims to demonstrate another 30 vehicles and **Hyundai** plans for 32 fuel cell cars. **Nissan** and **Toyota** will collectively deploy 65 fuel cell vehicles while **BMW** aims to bring 15 hydrogen fuelled internal combustion engine (H2-ICE) cars onto the road.

Hi Way Initiative

The project, funded by US federal government with only US$ 2 million and supported by a team of industry and academia, aims to establish a hydrogen highway in New York State. The first station is planned to open in Latham in 2005.

HYCHAIN

The objective of the HYCHAIN Project (Ruhr-Alps-Milan Hydrogen Supply Chain Integrated Project) is to bring three large European communities together to demonstrate different ways to implement a hydrogen supply chain from production to distribution and use of the fuel in transport and stationary applications. There are 65 project partners, including companies such as **Air Liquide, Besel, CEA** and **ZBT**. The total estimated budget for this project is Euro 40 million starting in 2005.

Hydrogen Corridor or Hydrogen Highway 2

Canadian fuel cell companies are working on a model for a 900 kilometres long hydrogen corridor with a number of filling stations along one of the major roads from Montreal to Windsor (across the border from Detroit). The project is part of a wider, Cdn$ 130 million (US$ 95 mln) government effort to push fuel cell and hydrogen development and demonstration. The project is still in its early stages but could be finalised within the next year.

HyNor

The Norwegian HyNor Project aims to demonstrate the implementation of a hydrogen energy infrastructure along a 580 km (360 miles) long major road between Oslo and Stavanger during 2005 to 2008. Various companies, including **Norsk Hydro, Shell Hydrogen**, **Statkraft** and others will construct up to 7 hydrogen filling stations to run a variety of vehicles including buses, taxis and private cars.

HyNor planned infrastructure (Source: HyNor)

Illinois Hydrogen Highway (2H2)

The Illinois Hydrogen Highway, a network of demonstration projects to promote hydrogen-based technologies in Illinois, was kicked off in June 2004 with a public discussion about the project and its implications. The Illinois Hydrogen Highway was first conceived as part of the Coalition's Illinois 2H2 report "The Hydrogen Highway: Illinois' Path to a Sustainable Economy and Environment" in March 2003.

The Illinois 2H2 Partnership, under the direction of the Illinois Coalition, is working to build a demonstration project at the Greater Northwest Chicagoland Airport in Rockford. This project will combine solar, wind, and hydrogen technologies to fuel airport vehicles and provide combined heat and power for an airport building. The Rockford airport project is the second hydrogen fuelling station to be proposed along I-90 since the Coalition report was released. The first is at the Gas Technology Institute's suburban Des Plaines headquarters. The timelines for this project are not clear.

SINERGY

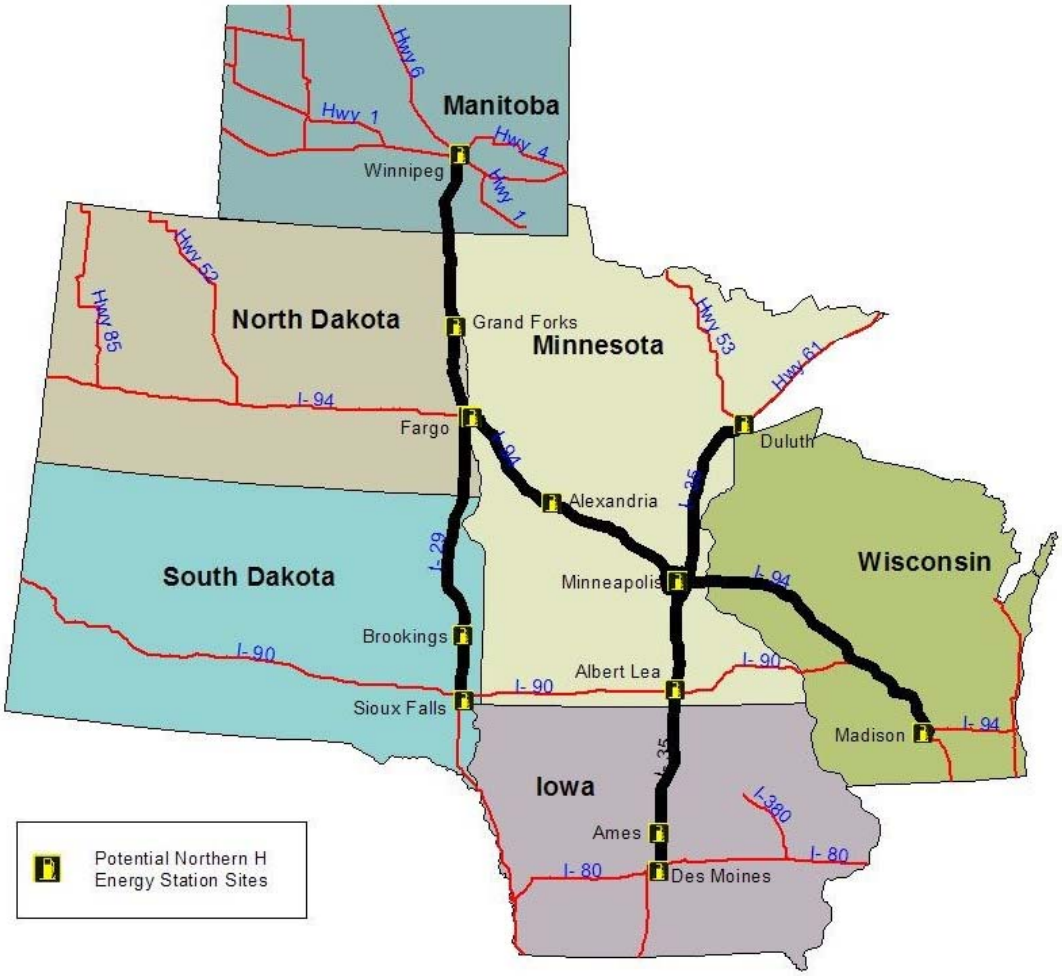
The **Singapore Economic Development Board**'s (SEDB) SINERGY programme ("Singapore Initiative in Energy Technology") promotes the development and commercialisation of new technologies in the area of alternative energy. In 2005 BP is planning to open the second hydrogen refuelling station in Singapore with on-site hydrogen production utilising electrolysis technology by **Singapore Oxygen Air Liquide**.

The Northern H

The Northern H is a project to establish a multi-fuel 'Hydrogen Network' in the Upper Midwest, USA. The project is led by the **Upper Midwest Hydrogen Initiative**, an industry organisation which aims to produce and provide hydrogen made from wind, biomass, solar, hydro and coal resources. The plan is that about 9 or 10 stations will be placed roughly 200 km apart which should be sufficient to allow a hydrogen-powered vehicle to traverse the length and width of the system. Each Northern H Energy Station would likely demonstrate a different renewable or carbon-neutral hydrogen production option and vehicle type, tailored to each jurisdiction's strengths and economic goals. By 2010, stations are planned to link urban centres along key

trade corridors across Manitoba, the Dakotas, Minnesota, Iowa and Wisconsin, ultimately linking with **Illinois' Hydrogen Path** planned along I-90. The project's objectives for 2004-2005 are to work with communities to identify suitable sites and recruit project partners.

This project was referred to as **Northern H2 Corridor Initiative** in our previous survey and is still not financed.



The Northern H network plan (Source: Upper Midwest Hydrogen Initiative)

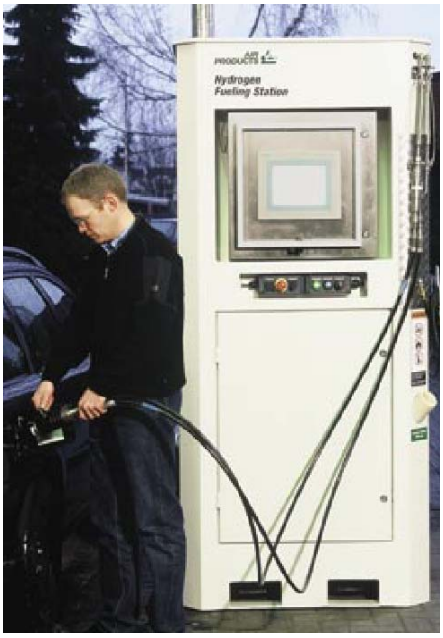
We are expecting more demonstration projects to come online as there is a growing trend of producing hydrogen through renewables for use in internal combustion engines to reduce emissions. For example, in Tasmania, which is rich in renewable energy, the coalition created by Hydro Tasmania is planning a move towards the hydrogen economy. Its short term strategy is to convert over 1000 internal

combustion engines to run on hydrogen because fuel cells, in its view, are not yet economic. This initiative will require a substantial refuelling infrastructure.

Key Players

Air Liquide is an industrial gas company, specialising in the supply of industrial and medical gases, including hydrogen. The company operates 35 hydrogen production units throughout the world mainly for industrial use. Air Liquide demonstrated its prototype hydrogen service station at the 6th Challenge Bibendum (October 2004) organised by Michelin at the Shanghai International Circuit. Three similar stations are operating around the world in clean urban transport projects in Kawasaki, Luxemburg and Madrid. The company is working with the **French Nuclear Research Agency** (CEA) on hydrogen supply systems and hydrogen storage. The company's Advanced Technology Division (DTA) is working on hydrogen storage (liquid and high pressure storage for vehicles) and hydrogen dispensing units.

Air Products & Chemicals produces hydrogen and equipment for hydrogen separation and purification. The company is active in developing an infrastructure of hydrogen distribution for use in fuel cells and has been involved in various high profile demonstration projects around the world. In addition to its mobile filling facility and a small stationary hydrogen fuelling unit ("Series 100") the company has also developed a totally integrated vehicle fuelling system ("Series 200") providing storage and dispensing that can use either hydrogen generated on-site or a distributed hydrogen supply. The latter was installed at the BP retail site in Singapore and has a capacity of dispensing 70 kilograms of hydrogen per day. Air Products is collaborating with **Proton Energy Systems** on two integrated vehicle fuelling systems to be built in California this year. It is also working with **BMW, ConocoPhillips, Honda, Nissan** and **Toyota** on other projects.



Air Products fuelling station Series 100 (Source: Air Products)

Babcock Hitachi (BHK), a subsidiary of **Hitachi**, has been working on on-site hydrogen production units. BHK's reforming technology was used for the Oume hydrogen station in Japan, one of ten constructed as part of the Hydrogen & Fuel Cell Demonstration Project (JHFC), where the company also completed the overall system integration.

BC Hydro, a Canadian utility company, is looking at developing a hydrogen infrastructure in British Columbia. The company has two subsidiaries: **BCHydroGEN** and **Powertech Labs** which have been involved in the evaluation, development, certification testing, and retesting of compressed hydrogen systems for vehicles. BC Hydro has increased funding for its Hydrogen & Fuel Cell Programme for financial year 2005. Together with BC Hydro, **Stuart Energy** (now **Hydrogenics)** and **Dynetek**, Powertech Labs have initiated the Compressed Hydrogen Infrastructure Program CH2IP.

The **BOC Group**, an international industrial gas supplier, is working on hydrogen energy projects across the globe. The company built two refuelling stations with **BP** to supply hydrogen for a fleet of fuel cell buses in London and Perth. It is also contributing funding, design and construction expertise for two fuelling stations as part of Canada's Hydrogen Highway project. BOC is working with **Cellex** to provide the indoor hydrogen refuelling facilities to power fuel cell forklift trucks

BP, one of the world's largest energy companies, is a key player in hydrogen demonstration projects around the world. BP is a partner in the CaFCP and a supplier of refuelling infrastructure to CUTE and the Singapore Clean Cars for Clean Cities Programme. In 2005 BP is planning to open the second hydrogen refuelling station in Singapore with on-site hydrogen production utilising electrolysis technology by **Singapore Oxygen Air Liquide**. The company has also announced its participation in further hydrogen refuelling demonstrations projects in the USA and China. BP and its German subsidiary **Aral** are working on hydrogen fuel and infrastructure issues with a number of organisations, including **DaimlerChrysler, Ford** and **General Motors**.

ChevronTexaco Technology Ventures (CTTV) is involved in design and construction of demonstration fuelling stations with a dual use for hydrogen generated on site from natural gas. The hydrogen will refuel vehicles and excess hydrogen will be used in a stationary fuel cell to meet the station's electricity needs. CTTV is leading one of the project teams consisting of **Hyundai Motor** and **UTC Fuel Cells** under the DOE's "Controlled Hydrogen Fleet and Infrastructure Validation and Demonstration Programme". In 2004 the company opened the first of six planned hydrogen fuelling stations in Chino, California under this project. CTTV is working with **Hydrogenics** to integrate a fully packaged hydrogen generator based on ChevronTexaco's natural gas reforming technology.

Dynetek designs and manufactures lightweight fuel storage systems for compressed natural gas, compressed hydrogen and industrial gases. Its hydrogen fuel storage systems have been incorporated in many fuel cell vehicles and buses, including those developed by **DaimlerChrysler**, **Ford**, **Hyundai**, **Mazda**, **Nissan** and **Toyota**. Dynetek is also developing ground storage systems for dispensing compressed hydrogen, bulk transport systems and mobile fuelling stations, designed for hydrogen fuelling demonstrations.

Ebara, normally linked to **Ballard** due to its small stationary fuel cell joint-venture **Ebara Ballard**, is also working on the development of hydrogen refuelling systems, which combine solar generation units with hydrogen generation systems made by partner company **Norsk Hydro Electrolysers**. Ebara aims to create a refuelling system which emits no carbon dioxide.

ECD Ovonics is working on hydrogen storage development using metal hydrides. The company is also developing an integrated renewable hydrogen generation storage system that uses photovoltaics to electrolyse water into oxygen and hydrogen and stores the resultant hydrogen in metal hydride storage devices. In order to bring metal hydride systems into full commercial production for emerging fuel cell markets ECD Ovonics has formed **Ovonic Hydrogen Systems**. The latter develops on-board and stationary hydrogen storage systems and stand-alone hydrogen refuelling stations for fuel delivery to vehicles, standby and UPS systems.

Stand-Alone Ovonic Hydrogen Refueling Station (Source: Ovonic Hydrogen Systems)

Fueling Technologies International (FTI) is a manufacturer of dispensing systems for hydrogen, natural gas and propane for both stationary and mobile applications. FTI installed its first hydrogen dispenser for **SunLine Transit** (located in California) and since then, has manufactured several more hydrogen dispensers for numerous locations worldwide including the first mobile hydrogen fuelling system in China for the Bibendum Challenge, which took place October 2004 in Shanghai.

Refuelling system for the Bibendum Challenge in Shanghai (Source: FTI)

General Hydrogen produces a range of hydrogen dispensers from simple, manual units for industrial use to full-function dispensers for more demanding consumer applications. With its strategic partner **Air Products** the company provides complete hydrogen fuelling solutions for Hydricity Pack customers. Hydricity Pack is a fuel cell developed by General Hydrogen that can replace lead acid batteries in industrial vehicles. Additionally, the company is producing a range of hydrogen storage systems.

General Hydrogen's Industrial Fuelling Systems (Source: General Hydrogen)

H2fuel is a joint venture between **Unitel Technologies** and **ReliOn** (formerly Avista Labs). The company develops compact hydrogen generators based on technology developed through a joint research project with **Argonne National Laboratory**. The device incorporates a catalyst that can convert commonly available fuels like gasoline, natural gas, propane, and methanol into the hydrogen gas needed to power many fuel cells.

H2Gen was until recently focused on research and development of hydrogen generators. Currently, the company is taking the next step of introducing its HGM (Hydrogen Generation Module) to the market. There will be 6 units in the field by the end of 2005 aiming for full commercialisation in 2008. The HGM is a methane steam reformer, which uses natural gas as a feedstock to produce hydrogen targeting the distributed energy market.

HERA Hydrogen Storage Systems develops solutions based on its hydride technology for automotive, transportation and hydrogen distribution applications including hydrogen storage. In partnership with **BOC** and **MRT** (Membrane Reactor Technologies), HERA is working to develop and demonstrate advanced hydrogen generation and delivery systems under a DoE grant received in December 2004. The goal is to deliver low-cost, high-purity hydrogen to industrial users, vehicles and stationary/mobile power plants. HERA has also been working with other companies including **Hydrogenics** and **Siemens**.

Hexion, a privately owned company, is using steam reforming technology in combination with Pressure Swing Adsorption in its hydrogen production units. These can be used to convert fossil fuels as well as renewable fuels to a high purity hydrogen stream. In February 2005 the DUOGEN project kicked-off where Hexion acts as the coordinator and cooperates with **Ballast Nedam**, **ECN**, **Nedstack** and **Nexus Global** to develop technology with which hydrogen and electricity is generated using a single integrated system. The "DUOGEN-generator" can be placed at a fuelling station and provide hydrogen to a dispenser for fuelling cars. When no cars are there to be fuelled, the hydrogen is fed into an integrated fuel cell stack and makes electricity. Hexion's subsidiary **Hexion Components** is working on metal hydride storage devices.

Hydro is one of the largest energy companies in Scandinavia with longstanding and wide experience in hydrogen-related research. It is participating in European hydrogen programmes (CUTE, ECTOS, CEP), and holds a stake in **Icelandic New Energy**, which aims to phase out the use of fossils fuels in Iceland in favour of hydrogen. The company's subsidiary, **Norsk Hydro Electrolysers**, supplies water electrolysis equipment and compression, purification, storage and gas handling

systems providing a complete solution for hydrogen fuelling stations as well as industrial applications and distributed energy systems.

Hydrogenics is developing three different product ranges: fuel cell power systems, test equipment and hydrogen generation/refuelling systems. Recently it has finalised the acquisition of Stuart Energy, a developer and integrator of hydrogen infrastructure products based on alkaline electrolysers. Before this purchase Hydrogenics developed its own refuelling systems with PEM electrolysis. One of its products, the HyLYZER refueler was installed at Exhibition Place refuelling station as part of Toronto's Hydrogen Village project. Hydrogenics is working with **ChevronTexaco Technology Ventures** to integrate a fully packaged hydrogen generator based on ChevronTexaco's natural gas reforming technology. At the end of April it was announced that Hydrogenics and Prince Edward Island Energy Corporation will lead a consortium of industry and government partners to develop Canada's first wind-hydrogen village demonstration.

HyRadix is working on the development and commercialisation of hydrogen generation technology for fuel cell and small industrial markets. HyRadix fuel processors produce a hydrogen-rich gas from natural gas or LPG and can be applied to residential and commercial PEM fuel cell systems, hydrogen vehicle fuelling stations and industrial hydrogen applications. At the end of April 2005, the company announced that its hydrogen fuel generator had completed a full year of operation in Thousand Palms, California providing hydrogen for HCNG and fuel cell buses and vehicles.

ILT Technology is a manufacturer of auto body and chassis parts as well as a producer of industrial gases. The company's gas division sells hydrogen generators under its PIEL brand. The company aims to strengthen its activities to play an important part in the emerging fuel cell vehicle refuelling technology sector.

Iwatani International is a Japanese gas and energy supplier. The company has been working with hydrogen for about 50 years and holds the leading share (40%) of the hydrogen market in Japan and was the first company to operate a liquid hydrogen plant there. Iwatani has also supplied equipment and hydrogen to various Japanese demonstration projects, including the Japan Hydrogen and Fuel Cell Demonstration Project, WE-NET and some local projects. Iwatani is currently

conducting an experimental study of a new filling station concept, which combines the compressor, glow meter and other equipment. These efforts could bring a fuelling facility's cost down by two thirds. Additionally, the company has leased a **Toyota** fuel cell vehicle to test drive.

Linde offers various industrial gas products and a whole range of gas applications hardware, including fuelling technology. Together with partners, including **LB-Systemtechnik**, **MAN** and **Siemens**, the company has built various fuel tanks. Linde is also involved in various German hydrogen filling and bus demonstration projects, including the Munich Airport project, the fuelling stations in Berlin and others. Furthermore, Linde is involved in a PEM fuel cell forklift truck demonstration project together with **Proton Motor Fuel Cell** and **Still**. Linde developed and constructed a mobile liquid hydrogen filling station and a tank for the Hydro-Gen3 car that were utilised during the 10,000 km "Opel Fuel Cell Marathon" in May 2004.

The company's subsidiary, **Linde Kryotechnik**, is working on cryogenic research and hydrogen liquifiers. The company was formed out of research activities in this field from Linde, **Sulzer** and the **Paul Scherer Institute** (PSI).

MesoFuel, a subsidiary of **Intelligent Energy**, is developing hydrogen generation systems for on-demand hydrogen from ammonia, methanol, natural gas and liquid fuels. The units are based on the company's "MesoChannel" reactor systems and membrane separation technologies.

Millennium Cell is working on technology to safely store hydrogen. The so-called "Hydrogen on Demand" system releases the hydrogen stored in sodium borohydride solutions by passing the liquid through a chamber containing a proprietary catalyst. This technology has been fitted to a number of prototype fuel cell vehicles. A five kilowatt system designed to mix solid fuel pellets (chemical hydrides) into a solution to produce hydrogen on demand was supplied to the US **DoD Fuel Cell Test and Evaluation Center**. With a recent DoE grant the company began collaboration with **Pacific Northwest National Lab** to develop hydrogen generation systems that meet the DoE's hydrogen storage efficiency targets. As part of this programme, it is working with **Los Alamos National Lab**, **Rohm and Haas**. Millennium Cell also has joint development programmes with other companies, including **Air Products, Ballard, DaimlerChrysler** and **US Borax**.

Mitsubishi's Energy Development Business Unit is engaged in a wide range of new energy-related businesses including fuel cells and hydrogen. The company has developed an electrolysis hydrogen production system that is more compact and lower-priced than conventional systems. In June 2004 Mitsubishi established **H3 Energy**, a company engaged in development, manufacturing, and sales of water electrolyser High-pressure Hydrogen Energy Generators (HHEG). At the same time, **Nippon Mitsubishi Oil** is working on the development of liquid fuel that can be used in fuel cell cars, while another subsidiary, **Mitsubishi Heavy** has developed a mobile hydrogen production system which is mounted on a trailer.

Pdc Machines designs, engineers and manufactures compressors for filling hydrogen storage vessels for stationary, mobile and portable fuel cell applications. The company's products are used in numerous filling stations worldwide and customers include all major players in this field, such as **Air Liquide, Air Products, DaimlerChrysler, Dynetek, ECD, Honda, Hydrogenics, Plug Power, Proton Energy** and others. One of the new additions is the next generation of diaphragm compressors for hydrogen service capable of discharge pressures of 15,000 psi for fuel cell applications.

Plug Power, a leader in the development of small stationary fuel cell systems, is also working on hydrogen generation units. The company's GenSite system has been demonstrated over 380 field installations. In the beginning of 2005 Plug Power was awarded a contract to provide the refuelling infrastructure for fuel cell vehicles leased by the state of New York and will partner with **Air Products and Chemicals**, **Homeland Energy** and **Honda** for this project. Plug Power is continuing its work with Honda on the next phase of the Home Energy Station's development which is designed to provide electricity and heat to a house while offering hydrogen fuel for a fuel cell vehicle.

Proton Energy, a subsidiary of **Distributed Energy Systems**, designs and manufactures electrochemical products for hydrogen production and fuel cell systems for power generation and energy storage. In January 2005 Proton started work with the University of Nevada, Las Vegas Research Foundation on developing a hydrogen filling station capable of operating on solar power for installation in Las Vegas, Nevada. The project's goal is to produce hydrogen at higher pressures and it will also

address the challenges presented with integrating renewable energy sources with water electrolysis. The company will also supply its PEM electrolyser for a station in Burlington, Vermont.

Praxair, a leading industrial gas and hydrogen supplier has been working with materials providers, device suppliers, end-use customers and government on the development of new clean fuel technologies. The company is leading a US DoE team in the development of a new generation of clean transportation fuels. Praxair is a member of the **California Fuel Cell Partnership**, the **National Hydrogen Association** and supplies the Sacramento facility with hydrogen. The company has used its expertise in several development projects with customers including BP, DaimlerChrysler and General Motors. In late 2004 Praxair and **BP** opened a prototype retail-friendly hydrogen fuelling station at the Los Angeles International Airport, which will fuel the airport's fleet of utility vehicles.

Quantum Technologies is a designer, integrator and manufacturer of packaged fuel systems for fuel cells and alternative fuel applications in the transportation, fuel cell stationary power generation and hydrogen refuelling infrastructure markets. The company's core competencies are gaseous fuel storage, fuel metering, electronic controls and fuel system integration. It has developed and demonstrated all-composite hydrogen storage tanks that store hydrogen at 700bar that has been certified for use. Quantum has developed two models of transportable hydrogen refuelers: the HyHauler and the HyHauler Plus which it is trying to commercialise with the major automakers and the US Army. The company has commercialisation alliances with **General Motors**, **IMPCO** and **Sumitomo.**

QuestAir Technologies develops and supplies gas purification systems for hydrogen refuelling stations, fuel cell power plants, as well as to already established markets such as biogas production and natural gas processing. The company has joint development agreements with Shell Hydrogen and a collaboration with **FuelCell Energy**. QuestAir's system purifies gas streams containing hydrogen for use in industrial processes, hydrogen fuelling stations and stationary fuel cell power plants. The company states that its unit delivers higher efficiency than conventional Pressure Swing Adsorption (PSA) systems through an optimised process and rotary valve technology. Its hydrogen purifier was also installed at **ChevronTexaco**'s site in Chino, California.

Shell Hydrogen, a subsidiary of oil conglomerate **Royal Dutch Shell**, and Japanese joint venture **Showa Shell**, is developing business opportunities related to hydrogen and fuel cells. Shell Hydrogen is a member of the **California Fuel Cell Partnership** and is responsible for several fuelling stations of the CUTE/ECTOS project, while Showa Shell is taking part in the JHFC programme. At the end of 2004 the company commissioned a hydrogen filling pump at its station in Washington DC. The station sells both compressed and liquefied hydrogen.

Stuart Energy, a developer and integrator of hydrogen infrastructure products based on alkaline electrolysers, was recently acquired by **Hydrogenics**. The company's main product is the Stuart Energy Station (SES), which consists of a hydrogen generation, compression, storage and dispensing/power module. Stuart Energy's equipment has been used in many major demonstration projects, since it is able to refuel several vehicles a day. The company has agreements with some major organisations, including **Cheung Kong Infrastructure** (CKI), with which it has a joint venture to market SES products for power and fuelling in the Asia Pacific region; with **Dynetek** whose hydrogen storage systems are used by Stuart Energy; with **Ford Power Products**, whose hydrogen internal combustion engine (H2-ICE) technology is used in the SES power modules; with **Shell Hydrogen** to jointly develop home hydrogen refuelling products; and with **Toyota** to support the carmaker in its fuel cell programme. Additionally, Stuart Energy has supplier and distribution agreements with **Air Liquide, Air Products, BOC** and **Linde Gas** and is a strategic investor in the **Hydrogen Car Company** (HCC).

Sumisho Air Water, partly owned by **Air Water** and **Sumitomo**, is a leading provider of industrial gases in Japan. The company has developed a truck-based mobile hydrogen station in 2003 and sold one unit each to **Nissan** and **Toyota**. Sumisho is also distributing **Stuart Energy** hydrogen production systems and **Fueling Technologies** dispensing units in Japan.

Ztek is a developer of solid oxide fuel cells but has also been working on high temperature steam reformers, which enable the production of hydrogen on-site at existing gasoline stations. The company is a member of the **California Fuel Cell Partnership** and is collaborating with **Pacific Gas and Electric** (PG&E) to construct

and operate a hydrogen refuelling station at PG&E's Service Center in California. Ztek has received orders through its distributor in Japan and Taiwan for two hydrogen reformers for operational training and two commercial size hydrogen reformers for delivery in 2005.

Further References

For more information on the use of hydrogen for vehicles, please have a look at our Light Duty Vehicle Survey (March 2005), Bus Survey (December 2004) and our Niche Transport Survey (June 2004) at www.fuelcelltoday.com/surveys You can find our last year's Automotive Hydrogen Infrastructure survey by following this link http://www.fuelcelltoday.com/FuelCellToday/FCTFiles/FCTArticleFiles/Article_805_hydrogensurvey0504.pdf

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About the author

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