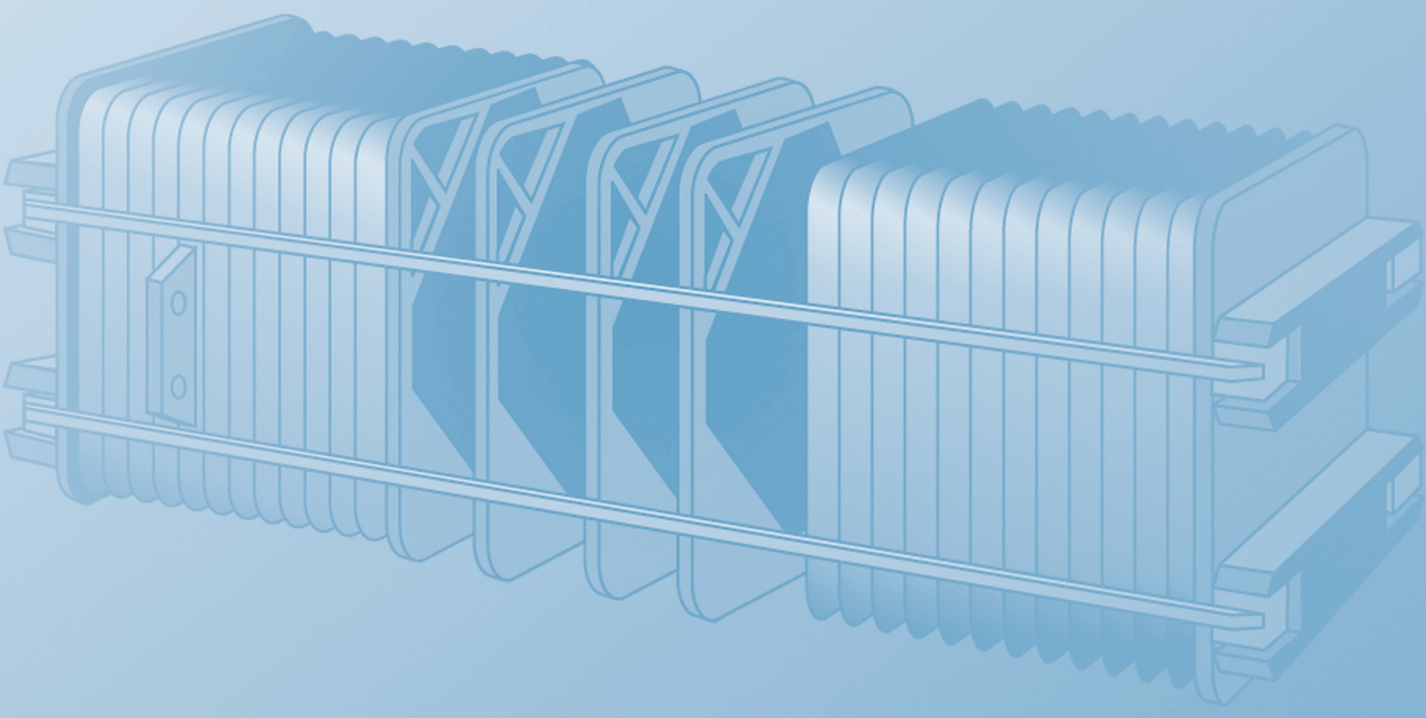
Fuel Cell Vehicle World Survey 2003

Breakthrough Technologies Institute
Washington, D.C. 20006

February 2004



U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Fuel Cell Vehicle World Survey 2003

Breakthrough Technologies Institute
Washington, D.C. 20006

February 2004

Notes

Organization. We have organized the auto industry reports alphabetically. The automobile industry is interconnected via cross ownership, and fuel cell research projects are often collaborations. This leads to some duplication in our reports, but we hope it helps the reader to find specific information quickly.

Quotes. The field visits and telephone calls were on a not-for-attribution basis. Any material appearing in quotations in the document comes from published sources.

Photographs and Art Work. We believe that all photos and artwork contained herein are in the public domain. BTI would be happy to attribute these materials to their author wherever appropriate. Please send comments and requests to Jennifer Gangi, Jennifer@fuelcells.org

Acknowledgement. The project managers acknowledge the work of Jennifer Gangi and Katherine Schein of the BTI staff who provided text and significant research support.

Disclaimer

Breakthrough Technologies Institute
1625 K Street, NW, Suite 725
Washington, D.C. 20006
Phone: (202) 785-4222; Fax: (202) 785-4313
Project Managers:
Robert Rose, e-mail: brose@fuelcells.org
William Vincent, e-mail: Vincent@fuelcells.org

DOE Program Manager: Donna Ho (202) 586-8000

Table of Contents

Table of Contents (Cont.)

Executive Summary

Fuel cell vehicles are rapidly appearing all over the globe. In less than 10 years, fuel cell vehicles have gone from mere research novelties to operating prototypes and demonstration models. At the same time, government and industry have teamed up to invest billions of dollars in partnerships intended to commercialize fuel cell vehicles within the early years of the 21st century.

The purpose of this project was to take a snapshot of the global fuel cell vehicle market as it existed at the end of 2003. Although certainly not comprehensive, it provides a good overview of the major fuel cell vehicle products and programs existing at the time.

The picture that emerged from this snapshot is truly amazing. Significant government/industry partnerships are operating in at least 11 major countries and the European Union. These partnerships are pursuing a variety of projects, including the development of "hydrogen highways," fuel cell buses, and fuel cell bicycles and scooters.

At the same time, we identified nearly 20 companies developing light-duty fuel cell vehicles and components. These include nearly all of the world's major vehicle manufacturers, such as Toyota, DaimlerChrysler, Ford, General Motors, Honda, and Mitsubishi. We also identified at least 12 companies or partnerships developing or demonstrating fuel cell buses. This group also included most of the world's leading players, including DaimlerChrysler, Man, Toyota, Volvo, New Flyer, North American Bus Industries, and New Flyer.

Although there are challenges ahead for fuel cell vehicles, one thing is clear: both government and industry appear fully committed to developing and deploying hydrogen- powered vehicles and the related infrastructure. Some countries, like Canada and Iceland, appear fully committed to transitioning from petroleum-based economies to hydrogen-based economies. Although this transition will take decades to complete, it appears that the necessary foundation is beginning to be developed.

Fuel cell vehicles hold great promise. They offer a zero-emission mobility option that is critical for the healthy development of the world's urban centers. They also have great economic potential, as shown by the significant investments made by the private sector to develop and demonstrate fuel cell vehicles.

We are pleased to present this snapshot of the fuel cell vehicle industry as it existed at the end of 2003. We hope that this report will provide a useful tool for policymakers, businesses, and others interested in exploring and developing fuel cell vehicles. We welcome any comments and suggestions.

Selected Research and Demonstration Projects
(12/2003)

COUNTRY	FUNDING
Canada	
Canadian Transportation Fuel Cell Alliance (CTFCA)	CAN$23 million (Canadian Government) to demonstrate fueling options for fuel cell vehicles
Hydrogen Early Adopters ("h2EA") Program	CAN$215 million (Canadian Government) for new concepts, including hydrogen highways
Fuel Cells Canada Hydrogen Village Partnership	Demonstration of hydrogen infrastructure in Toronto
Vancouver Fuel Cell Project	CAN$5.8 million over 3 years
Hybrid Fuel Cell Transit Bus Project (with Hydrogenics Corp.)	CAN$8 million (Natural Resources Canada: CAN$2 million in Phase I, CAN$1 million Phase II. Hydrogenics and its partners are contributing the remainder)
China	Chinese Government pledged $20 million a year for 5 years to FCV research; Chinese Academy of Science to invest $12 million over 3 years on hydrogen technology; GEF will provide $12 million for fuel cell bus development; national and local governments will provide $20 million, with $4 million pledged from private companies
Europe	
European Union	€2.8 billion on hydrogen by 2015; €500 million by 2007; €1.2 billion in 2007–2012
CUTE (Clean Urban Transport for Europe)	EU is contributing €18.5 million to demonstrate fuel cell buses and fueling infrastructure in nine cities (3 buses in each city)
France	€40 million over five years for Clean Vehicles; €5.8 million allocated to fuel cells
Germany	~€55–€60 million in combined federal and state funding for power generation and vehicle development and demonstration
Italy	~€15 million annually, proposed to double to ~€30 million annually for the next three years
Iceland	
Ecological City Transport System (ECTOS)	Demonstration of three fuel cell buses; hydrogen infrastructure activities. ~€9.5 million, €2.8 million from EU, ~€6.7 million from the commercial partners (Shell, VistOrka hf, Norsk Hydro, and DaimlerChrysler)

Japan	
Japan Hydrogen & Fuel Cell Demonstration Project (JHFC)	Multi-company road demonstration. Japanese Government contributed ¥2 billion in 2002 and ¥2.5 billion in 2003
Methanol FCV Project	Ministry of International Trade and Industry will contribute up to ¥300 million (of the ¥1 billion project cost)
United States	
Freedom Car/Hydrogen Fuel Initiative	Will invest total of $1.7 billion to develop hydrogen fuel cells, hydrogen infrastructure, and advanced automotive technologies
National Fuel Cell Bus Technology Initiative (NFCBTI)	Proposing to allocate $150 million in U.S. federal transportation funding for FC bus development and deployment
California Fuel Cell Bus program	Program budget is $18,450,000 for a total of seven buses in three jurisdictions
World Bank/GEF Fuel Cell Development Program	Bus demonstrations in Brazil, China, Egypt, India, Mexico. GEF commitment of 12/03: $24.2 million

Commercialization Timetables[1]

COMPANY	Comments
BMW	First commercial sales before 2008 (gasoline-liquid hydrogen hybrid 7-series, with fuel cell APU a possibility in later models); 25% market penetration after 2020 (if infrastructure can be developed).
DaimlerChrysler	"Fit for daily use" stage 2004 through 2007; "ramp up" and full commercialization stages starting 2010.
Fiat	States "long way from commercialization." Currently conducting on-road demonstration in Milan, Italy.
Ford	Commercialization timetable consistent with DOE's (2012–2015). Interested, with Mazda, in hydrogen combustion engines.
GM	Plans to establish high-volume fuel cell and fuel cell vehicle production capabilities by 2010; looking to sell hundreds of thousands of fuel cells and FCVs by 2020 by entering power generation markets first.
Honda	Announced plans to build 300 FCVs a year for sale in the United States and Japan. Developing its own systems — agreement with Ballard ends in 2005. Continuing to expand vehicle and infrastructure demonstrations.
Hyundai	Plans, with Kia , to test 32 FCVs in the United States beginning 2004; suggests it may sell 10,000 FCVs in Korea by 2010, with commercial production by 2020.
Mazda	Target of 2007 for initial production of hydrogen rotary IC engine.
Mitsubishi	Grandis approved for public roads in Japan in November 2003; plans to commercialize an electrolyzer to support fuel cell vehicles 2005.
Nissan	Long-range fuel cell production strategy is not public; has said it expects to have some FCV production capabilities by 2005.
PSA/Peugeot Citroën	Says technical barriers to FCVs would prevent consumer purchases before 2015; electric hybrids with small fuel cell APUs as range extenders could become commercial after 2005. Focus is on non-hydrogen fuels.
Renault	Unveiled its first and only functional FCV in 1997; dated plans call for prototypes of solid oxide fuel cell APUs by 2008 (a scenario now considered unlikely) and commercial products by 2015; announced plan to have FCV in production by 2010; working with Nissan on gasoline reforming.
Toyota	Asserted FCVs will not be commercial before 2010; generally supports DOE timetable of commercialization decision by 2015.
Volkswagen AG	No timetable announced. Demonstrating a van with a fuel cell APU. Audi, part of the Volkswagen Group, displayed its first-ever fuel-cell-powered vehicle (an Audi A2) powered by a 70-kW Ballard PEM fuel cell.
Bicycles and Scooters	Most companies working on fuel-cell-powered scooters project market introduction in 2004, although that target appears very ambitious.
Boats, Yachts, Submarines	Siemens AG has agreed to supply Greek navy with PEM modules for use as APUs/range extenders in 3 class 209 submarines, delivery to begin 2004.

[1] Data in this table generally represent public statements or inferences drawn from public statements. In many cases, officials in a given company have expressed conflicting views and estimates. Timetables announced in the 1990s generally have slipped.

Introduction

Interest in fuel cell vehicles has skyrocketed over the last 10 years. Government and industry across the globe are developing fuel cell cars, buses, and specialty vehicles, like golf carts and fork lifts.

The Breakthrough Technologies Institute, Inc. (BTI), entered a cooperative agreement with the U.S. Department of Energy (DOE) in 2002 to survey fuel cell vehicle developers, selected energy and component suppliers, and interested government agencies. Our purposes were to:

- Research, assess, and evaluate the current status, strategies, policies, and future plans of governments, major energy companies, major motor vehicle manufacturers, and developers of key components of fuel cells designed for use in motor vehicles in countries outside the United States;
- Attempt to measure the technical progress of companies in international markets against DOE's targets and goals; and
- Assess commercialization plans of companies and government programs to support commercialization.

The goals of the Fuel Cell Vehicle World Survey were revised twice to reflect the results of project outreach activities and the fast-changing fuel cell vehicle landscape. Originally, the goals were quite technical, but as the project progressed, the focus shifted to an overview and report on the status of demonstrations.

The result is this snapshot of fuel cell motor vehicle development and major vehicle demonstrations around the globe. We hope it is useful for U.S. policy makers tracking the worldwide race to commercialize fuel cells and for U.S. companies interested in participating in the coming hydrogen economy.

This is an extremely fast-paced arena. New vehicles are being unveiled and component announcements made at an extraordinary rate. We have made every effort to provide timely and up-to-date information. We welcome corrections, additions, and comments.

The project attempted to gather as much information as possible directly from automobile manufacturers, fuel cell component companies, major energy companies, and governments. There are hundreds, if not thousands, of companies throughout the world working on some aspect of vehicular fuel cell development. The number of governments making significant investments in the development of fuel cells is increasing. To help us reach as many companies as possible, BTI contracted with several consultants, each knowledgeable in a particular region of the world. Extensive additional research was required to assure that BTI adequately surveyed the field.

Three survey methods were chosen: site visits, telephone interviews, and mailed questionnaires. Generally, BTI selected companies that were large enough, well financed enough, or innovative enough to be likely to play a significant role in the development and/or eventual commercialization of fuel cell automobiles or buses.

One of the early challenges to the study's success involved motivating potential respondents to participate. BTI, in consultation with DOE, decided that priority participants would appreciate a briefing by DOE officials in conjunction with a site visit. The event would be viewed as an exchange of useful information by all of those participating. Site visits were designed to be led by a consultant accompanied by DOE officials.

To encourage the participation of phone and mail respondents, a briefing paper outlining the current U.S. government approach to and initiatives supporting fuel cells for vehicular use was prepared for distribution.

We conducted a total of 53 site visits involving consultants and DOE representatives. Site visits were considered useful to both BTI and DOE personnel and the respondents. Meetings were held in Italy; Germany; the UK; China; Japan; South Korea; and Ottawa and Vancouver, Canada, and averaged two to three hours in length.

We distributed more than 150 questionnaires and made hundreds of telephone calls and additional site visits. Companies responding range widely in capitalization levels and workforce sizes.

Although some companies refused to participate in the study, many respondents were willing to discuss their business activities and their views on fuel cell development and the eventual commercialization of fuel cell vehicles as long as they were assured that their responses were not attributable. There was a greater reluctance to share technical data. We found similar attitudes in our telephone surveys and follow-up consultant visits. Overall, participants were extremely reluctant to share performance data and business projections.

A discussion of the project, including lists of consultants, visits and companies contacted, can be found in the appendices.

Major Government-Supported Fuel Cell Vehicle Projects

Government support for fuel cell projects is critical to the development of fuel cell technology. Among other things, governments provide capital for pre-commercial research initiatives, encourage technology transfer, create incentives, and serve as early adopters of fuel cell products. This section summarizes major government-sponsored fuel cell activities.

Australia

Both the Commonwealth and Provincial governments are involved in demonstration activities designed to move Australia toward a hydrogen economy.

STEP

The government of Western Australia has launched a wide-ranging vehicle demonstration program called the Sustainable Transport Energy Program (STEP). The program includes research and field trials involving biofuels, hybrid vehicles, and fuel cell buses. Three DaimlerChrysler/EvoBus hydrogen fuel cell buses will be placed on normal service routes in Perth for two years from late 2004 to 2006.

Overall program costs are estimated at AUS$14 million over 5 years, including AUS$7.5 million for the buses. The Western Australia Government has committed AUS$8 million, with BP and the Australian Commonwealth Government each committing AUS$2.5 million.

The Western Australian Government, through the Department for Planning and Infrastructure, will own the buses. They will be operated as part of the Transperth public transport system by Path Transit.

BP is supplying the hydrogen fuel for the trial, produced from its oil refinery at Kwinana.

The project hopes to determine the critical technical, environmental, economic, and social issues facing introduction of hydrogen fuel cell buses; the Government's role in supporting a hydrogen based energy system; and what opportunities there might be for Western Australian and Australian industries.

National Hydrogen Study

The Australian Federal Resources Ministry released a National Hydrogen Study in 2003. The study suggested that by 2030, Australia might operate 20% of its vehicle fleet fuel on hydrogen. The study recommended adopting a national vision for hydrogen, addressing codes and standards, participating in international research efforts, and establishing an Australian Hydrogen Group.

Also in 2003, an AUS$36 million "Energy Centre" was opened at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in New Castle, New South Wales. The Center is dedicated to demonstrating how industry and government partners can work together to promote sustainable energy.

The Centre will develop partnerships to research, demonstrate, and ultimately transfer technologies to the market. It will focus upon distributed energy and new-generation transportation that is based upon advanced drive technologies, intelligent transportation systems, and energy efficiency. The Centre also will house a "National Research Flagship," entitled "Energy Transformed," that will focus national research efforts on technologies that could lead to the development of an Australian hydrogen economy. Energy Transformed will include research into drive train, energy storage, and energy management technologies to advance hydrogen fuel cell vehicles.

Even the building is dedicated to demonstrating sustainable energy technologies, including solar, gas micro-turbines, and wind generators that will initially provide most of its power. In the future, there are plans to use fuel cells, a solar-thermal system, and a one-megawatt energy storage system.

CSIRO Energy Centre, NSW

Canada

Canada is aggressively seeking to maintain a major role in a global fuel cell and hydrogen industry. Canada currently is home to some of the world's leading fuel cell and hydrogen companies. According to one government web site, "Canada's long-term objective to maintain its position as a world-leader in the evolution of a hydrogen economy…"[2] Consequently, Canada has a number of interesting fuel cell partnerships and programs.

Canadian Transportation Fuel Cell Alliance (CTFCA)

The Canadian Transportation Fuel Cell Alliance is a CAN$23 million government initiative that will demonstrate and evaluate fueling options for fuel cell vehicles in Canada. The main objectives of the Alliance are to demonstrate greenhouse gas (GHG) reductions, evaluate different fueling routes for fuel cell vehicles, and develop the necessary supporting framework for the fueling infrastructure (including technical standards, codes, training, certification, and safety).

Different combinations of fuels and fueling systems will be demonstrated by 2005 for light-, medium-, and heavy-duty vehicles. The initiative also will develop standards and training and testing procedures related to fuel cell and hydrogen technologies. Funding for the Alliance is drawn from Canada's Action Plan 2000, a CAN$500 million greenhouse gas reduction program. The Alliance was announced in 2001.

The program will support several co-funded projects designed to provide a variety of "opportunities for learning and solving technical and economic issues associated with the introduction of fueling for fuel-cell vehicles."

The program has approximately 50 partners, from industry, municipalities, non-government organizations, federal and provincial governments, and universities.

Hydrogen Early Adopters ("h2EA") Program

In October 2003, the Government of Canada announced a commitment of CAN$215 million to create the h2EA program. The program, which is being run through Industry Canada, will demonstrate new hydrogen technology concepts designed to lead to a hydrogen economy for Canada.

The Government of Canada has expressed its intention to use the h2EA program to work with industry to create a "Hydrogen Team." It is envisioned that, among other things, the Hydrogen Team will demonstrate new concepts, such as "hydrogen highways" and "hydrogen villages." Specific goals for the program include:

---

[2] See http://www.tpc.ic.gc.ca/h2/en/

- Increased public, consumer, and investor awareness and acceptance of the hydrogen capability;
- Integration of hydrogen and hydrogen-compatible technologies;
- Development of hydrogen infrastructures;
- Development of skills and supply chain in the hydrogen industry;
- Development of codes and standards for the hydrogen industry; and
- Increased performance, reliability, durability, and economical viability of hydrogen and hydrogen-compatible technologies.

It is anticipated that three to five projects will be funded initially.

Fuel Cells Canada Hydrogen Village Partnership

In December 2003, Fuel Cells Canada, an industry association, announced the formation of a Hydrogen Village Partnership. The Hydrogen Village will "deploy and demonstrate" a variety of hydrogen infrastructure technologies in the greater Toronto area. Participants include government and private sector entities.[3] No budget was announced.

[3] The 27 participants include Air Liquide; Astris Energi, Inc.; Ballard Power Systems, Inc.; Bell Canada; BET Services; BC Gases; the city of Toronto; the city of Mississauga; the Centre for Automotive Material and Manufacturing; Dynetek Industries, Ltd.; Enbridge Gas Distribution; Enviromotive; Fuel Cell Technologies, Ltd.; General Hydrogen Corporation; Giffels Associate, Ltd.; HERA Hydrogen Storage Systems; Hydrogenics Corporation; John Deere ePower Technologies; Kinectrics, Inc.; KPMG, LLP; Ontario Power Generation, Pivotal Power; Purolator Courier, Ltd.; QuestAir Technologies, Inc.; Sarnia/Lambton Economic Partnership; Stuart Energy Systems, Inc.; and the University of Toronto at Mississauga.

China

Fuel-cell-related research has been under way in China since the 1950s, but serious interest in vehicles dates only to the mid-1990s, spurred by the Global Environmental Facility's (GEF's) interest in supporting an appropriate fuel cell bus demonstration in China (the GEF program is discussed in the next section). Since that time, China has made impressive progress. Passenger cars, two-wheel vehicles, and buses are being test-driven in the hope of making a major statement on hydrogen and fuel cells at the 2008 Beijing Olympics (which China has dubbed the "Green Olympics") and the 2010 Shanghai World Expo.

An estimated 60 organizations currently are involved in fuel cell research in China. Most of these organizations are research institutions, generally with a focus on PEM technology. An estimated three-fourths of the work focuses on vehicles.

Among the leaders is the Pan Asia Technical Automotive Center (PATAC) in Shanghai, a joint venture with General Motors and the largest Chinese auto company, Shanghai Auto Industry Corporation (SAIC). PATAC developed a functioning vehicle with modest initial support. General Motors is said to be increasing its research investment in China, and SAIC has its own independent program.

Several developers have multi-vehicle demonstration plans. For example, SAIC intends to put a small demonstration fleet on the road in 2005. Tongji University is expected to produce five to seven vehicles over the next few years, supported by government funding. There are plans for several updated minibuses and transit buses. There is even a fuel-cell-powered boat under test.

Driving this activity is China's transportation policy, which is encouraging the development of motorized transportation. China is building a substantial new highway infrastructure. Total passenger vehicle sales exceed 1 million units per quarter, including about 400,000 passenger cars, and year-to-year percentage increases are dramatic. Beijing and Shanghai, among others, have adopted policies to limit the use of bicycles.

At the same time, China is a net importer of oil. China also has large coal reserves that could be used to produce hydrogen.

In 2001, China increased its investment in fuel cell vehicle research, pledging about $20 million a year for five years. In 2002, the Chinese Academy of Science announced it would invest $12 million over three years on hydrogen technology, including PEM fuel cells.

Most recently, General Motors launched a full-scale attempt to convince the Chinese to move rapidly to a fuel cell vehicle future. In high-level visits late in 2003, GM suggested a hydrogen infrastructure could be built in tandem with the expanding gasoline infrastructure, allowing China to skip much of the internal combustion age and move directly to electrochemical fuel cell engines.

GM estimated a sufficient hydrogen infrastructure might cost $6 billion to $15 billion, a manageable number given that China pays roughly $22 billion for imported oil annually (2 million barrels/day at $30/barrel).

Passenger Cars and Buses

China has made remarkable progress from modest beginnings. In 1998, Tsinghua University built the first known fuel cell vehicle in China, a golf cart powered by a 5-kW stack supplied by Beijing Fuyuan Century Fuel Cell Power. A passenger sedan was shown in 1999. It is a mark of the team's progress that Beijing Fuyuan is now testing stacks up to 140 kW for use as bus engines.

Beijing LN Green Power Company partnered with Tsinghua and the Beijing Institute of Technology to build a fuel-cell-powered taxi, a passenger car, and a 12-seat bus, all unveiled in 2001. Tsinghua also integrated a fuel cell into a transit bus and is working with Samsung and Toyota on vehicle development.

Among the commercial leaders is PATAC, which developed a functioning vehicle with modest initial support, unveiling it in 2001. The vehicle, called the Phoenix, features a Buick minivan body and GM fuel cell technology. General Motors featured the vehicle, along with its HyWire, in a technology forum in China in 2002. GM is said to be increasing its research investment in China.

SAIC has an independent program. Working with Tongju University, SAIC unveiled the Chao Yue 1 in 2003, based on an old VW Santana sedan. SAIC hopes to field a test fleet in 2005. The company produces almost half of the passenger vehicles sold in China.

Shanghai Shen-Li High Tech Company Ltd. was founded in 1998. In its short lifetime, it has demonstrated a jitney, an automobile, a scooter, and an electric bicycle, using fuel cells up to 40 kW. It is working on a minibus that would use a PEM engine up to 80 kW.

Two-Wheel Vehicles

Because of its vehicle mix, China has pursued not only passenger cars and buses, but also two-wheel vehicles. The country already manufactures about 2.5 million *electric* bicycles, comparable to the total number of automobiles produced in 2001. Fuel cells are believed to have more desirable performance characteristics than batteries.

Suzhou Small Antelope Electric Bicycle Company has teamed with PALCAN to develop a fuel cell system to power its electric bicycle; a separate arrangement with Beijing Fuyuan aims to produce engines up to 5 kW for a range of two-wheel vehicles. Shanghai Forever Bicycle Company is also working with PALCAN to test fuel cell power on its electric bicycle and small scooter. Shanghai Shen-Li High Tech Company's activities are outlined above.

In Taiwan, Asia Pacific Fuel Cell Technologies Ltd. has produced several generations of fuel cell scooters. (See Specialty Vehicles section.)

Europe

Hydrogen has been a priority of the European Commission at least since 2001, when its Alternative Motor Fuel Communication suggested that by 2020, 20% of motor fuel should be from nonpetroleum sources and identified "a possible market share of 5% by 2020 for hydrogen." To date, Europe has focused much of its attention on fuel cell buses.

The Clean Urban Transport for Europe (CUTE) project (see below) was established in 2001, and a "contact group" was put to work to develop scenarios for meeting the 2020 targets. The EU leadership convened a Hydrogen and Fuel Cell High Level Group in 2002 to develop a vision statement, which was published in May 2003. One of the recommendations was creation of a European Platform for the Sustainable Hydrogen Economy with public and private participation. The first "General Assembly" is scheduled for early 2004.

Late in 2003, the EU announced a massive research program in energy, communications, and electronics that envisions spending tens of billions of Euro by 2015, including €2.8 billion on hydrogen. The plan sets a "down payment" for hydrogen of €500 million by 2007, with another €1.2 billion in 2007–2012.

CUTE

CUTE is a comprehensive demonstration of fuel cell buses in nine European Cities. The European Commission is contributing €18.5 million to the project. Buses began operating in 2003. When the project is fully under way, three Citaro buses will be operating in revenue service in each of nine European cities: Amsterdam, Barcelona, Hamburg, London, Luxembourg, Madrid, Porto, Stockholm, and Stuttgart. The buses will operate on existing routes alongside conventional buses. Fueling stations have been designed to test a variety of feedstocks, infrastructure strategies, and safety requirements in center cities. DaimlerChrysler will supply the Citaro fuel cell buses.

A companion project is ECTOS, a four-year project in Reykjavik, Iceland, which is also testing three Citaro fuel cell buses.

FEBUSS

The FEBUSS[4] project is a five-year program designed to develop a hydrogen-fueled 100-kW PEM fuel cell power module that is standardized for transit and stationary applications. Cost reduction is the main driver. FEBUSS began in 2002 and is backed by the European Union. FEBUSS includes a two-year test of two power modules to evaluate data on maintenance costs, system reliability, and other factors critical to market development.

FEBUSS was established under the premise that the best path to commercialization of fuel cells is a systems approach aimed at meeting end-user defined objectives and constraints. The project

[4] FEBUSS = **F**uel cell **E**nergy systems standardized for large transport **BUS**es and **S**tationary applications

brings together end-users, system designers, fuel cell component suppliers, and safety and regulatory specialists.[5]

The Fuel Cell Bus for Berlin, Copenhagen, Lisbon

Several European manufacturers and public transit agencies are participating in this project with financial support from the European Commission's Directorate-General for Transport and Energy under the ENERGIE program. The aim is to demonstrate a fuel cell bus using liquefied hydrogen in central cities. The bus will be operated, in turn, by the transit operators in Berlin, Copenhagen, and Lisbon. In addition, BVG (Berliner Verkehrsbetriebe), the Berlin transit agency, has ordered two double-decker fuel cell buses under a German Ministry for Economics program.

The filling station installed in 2002 at BVG's depot will be used for the fuel cell bus fleet that BVG anticipates putting into service in the coming years.[6]

CITYCELL

This hydrogen bus demonstration initially was a 48-month program designed to operate in four countries and involve five fuel cell buses, but as of mid-2003, it was only active in Spain, sharing the hydrogen filling station in Madrid with the CUTE buses. Irisbus is the bus supplier so far.

ENERGIE

ENERGIE, the non-nuclear energy program of the European Union, supports several fuel cell and electric vehicle transport projects. The program's goal is to identify CO_2 reduction strategies. Priorities in the transport sector are "to optimize combustion technologies using cleaner hydrocarbon fuels and other alternative fuels, such as hydrogen; to develop and demonstrate hybrid and electric propulsion systems, such as batteries, fuel cells, fuel processors and other energy storage and conversion devices and hybrid systems; to demonstrate innovative public and private transport systems by making comparative assessments of the energy efficiency, emissions, feasibility, reliability, safety, operability and economics of alternative vehicles; promoting the advanced transport technologies made in the EU."

---

[5] Partners include Axane Fuel Cell Systems; Alstom Transport; Centre National de la Recherche Scientifique; Institut National Polytechnique de Toulouse (INPT); Centre National de la Recherche Scientifique; Schneider Electric; Irisbus; TUV Saarland; Ineris; INTA; INPG; UJF and CNRS; Air Liquide; Commissariat a l'Energie Atomique; Johnson Matthey; Ineos Chlor; and SGL Technologies.

[6] Partners include MAN, HT Copenhagen, Air Liquide, Instituto Superior Técnico, CARRIS (Lisbon transit), MVV Consultants and Engineers, and the Berlin Senate.

Munich Airport Demonstration Project

The Munich airport project is a multi-company demonstration of hydrogen refueling stations and fuel cell and hydrogen-fueled vehicles. The airport has two fueling units, one providing gaseous hydrogen for three MAN buses and the other for refueling BMW liquid hydrogen ICE vehicles. The project began in 1999 and is funded until 2006. Ballard Power Systems and MAN recently announced additional shipments of fuel cell buses to the project in 2004. Proton Motors, Still and Linde plan to run a fuel-cell-operated forklift truck at the airport.

Clean Energy Partnership (CEP) Berlin

CEP is a consortium of nine corporate partners and the German Federal Government. The goal is to demonstrate hydrogen fuel for cars and buses. The partners – Aral, the BMW Group, Berliner Verkehrsbetriebe (BVG), DaimlerChrysler, Ford, GM/Opel, Hydro/GHW, Linde, and Vattenfall Europe – are supplying the infrastructure, technology, and vehicles for this five-year project. In 2004, a hydrogen fueling station is planned, and up to 30 vehicles will be tested.

World Bank/GEF Fuel Cell Bus Development Program

The mission of the Global Environment Facility (GEF) is to finance activities that address global biodiversity loss, climate change, degradation of international waters, and ozone depletion. Among other things, GEF helps cover the incremental cost of advanced technologies that yield a reduction in climate change gases in developing countries. GEF is supporting the demonstration of a planned 46 fuel cell buses in five nations: India, China, Egypt, Mexico, and Brazil. Fuel cell buses are eligible for GEF funding under its Operational Program #11: "Promoting Environmentally Sustainable Transport." Investigations began in 1995 with plan approval in 2000. All but India are in the "implementation" stage; India is in the "development" stage.

GEF has expressed concern over delays in the procurement process and possible delays in delivery of the buses.

China

The China project involves purchasing six buses and one fueling station each in Shanghai and Beijing and operating the buses a total of 1.6 million kilometers. GEF will provide $12 million of the estimated $36 million project cost. National and local governments will provide $20 million with $4 million pledged from private companies. Shanghai's plans call for a follow-on project that would operate during the 2010 World Expo.

Detailed technical specifications are complete and have been released to potential bidders. An official invitation to bid is expected to be released in February 2004, with a target date of March 2004 for a signed contract.

The project goals are cost reduction, operator experience, capacity building, policy development, and technical and scientific understanding. A series of activities will also focus on defining a detailed strategy for large-scale fuel cell bus implementation in China, which is planned as a follow-on to this initial project.

Egypt

The overall objective of the project is to introduce to Egypt a viable electric, hybrid-electric, and eventually fuel cell technology program, starting with the Giza plateau and the Cairo public transport sector. The multi-phase plan will start with testing a bus in various sites in Egypt; conducting economic, environmental, and societal studies; and training managers, engineers, and technicians. Two electric buses will be used in the tests, according to GEF, and a technology transfer and commercialization plan will be drawn up on the basis of the results. In 2003, GEF reported it has committed $748,000 to the project.

Brazil

The Brazil project is designed to help accelerate the commercialization of fuel cell buses using renewably generated hydrogen, with cost reduction an important secondary goal. In mid-2003, negotiations were under way with suppliers with a target date of June 2004 for signed supply contracts and the delivery of the eight buses by the year of 2006. The managers of the project are discussing options for information sharing with the Clean Urban Transport for Europe (CUTE) and California Fuel Cell Partnership. Negotiations were under way on a networking agreement within the context of the Urban European Commission "Controlling Urban Mobility Program (URB-AL)" for Europe-Latin America, "enabling information and knowledge sharing between European and Latin American cities, namely the cities of Porto, Barcelona, Mexico City and Sao Paulo," according to GEF. The GEF financial commitment as of mid-2003 was $12,274,000.

Mexico

The project aims at promoting "the development, manufacture and large-scale commercialization" of fuel cell buses in Mexico. A test fleet of 10 buses will operate in Mexico City for five years. A project strategy was approved early in 2003 and a consultant hired to develop an implementation plan. GEF funding early in 2003 totaled $5.1 million. A tender to potential suppliers was expected "soon."

India

At last report, the India project was still in the assessment stage. The goal of the operational phase is a bus demonstration "designed to contribute significantly toward achieving the long-term objective of reducing the costs of fuel cell buses to near-competitive levels in India." Initial GEF commitments totaled $300,000.

Iceland (ECTOS)

Iceland is committed to developing the first hydrogen-based economy. Rich in hydroelectric and geothermal energy and small in size, Iceland sees itself as an ideal laboratory for the conversion. Shell, the Icelandic holding company VistOrka hf, Norsk Hydro, and DaimlerChrysler founded a joint venture in 1999 called Icelandic New Energy (INE). INE's task is to evaluate hydrogen options and fuel cells for use in Iceland.

INE established the Ecological City Transport System (ECTOS) project late in 2000. ECTOS is a four-year project in Reykjavik that will test three hydrogen-fueled Citaro fuel cell buses. Hydrogen will be generated via electrolysis of water. The project was launched in March 2001. The buses will operate on city streets for two years. The project is running parallel with the CUTE project in Europe. The European Community is contributing €2.8 million. The balance of the estimated project cost of €6.7 million will come from the commercial partners.

Japan

Hydrogen & Fuel Cell Demonstration Project (JHFC)

The Japan Hydrogen & Fuel Cell Demonstration Project (JHFC) is a multi-year government-sponsored demonstration designed to evaluate fuel cell vehicle technology and begin the development of a hydrogen infrastructure. The project is also designed to educate the public about fuel cells and hydrogen safety. The Japanese government has committed to revising its transport and consumer safety regulations by 2005 to support a hydrogen infrastructure. JHFC will be directed by Japan's Ministry of Economy, Trade and Industry (METI). The vehicle tests will be overseen by the Japan Automobile Research Institute, and the hydrogen infrastructure evaluations will be overseen by the Engineering Advancement Association of Japan. The government's share of the project was ¥2 billion in 2002 and ¥2.5 billion in 2003.

Facilities for producing liquid hydrogen were designed in 2002, but Japan's fuel cell vehicle demonstration program began in earnest in 2003, with fuel cell vehicles from a field trial of eight car manufacturers, along with a fuel cell bus. Nine hydrogen stations are in development, designed to test a variety of feedstocks and fueling strategies, including desulfurized gasoline reforming, naphtha reforming, LPG reforming, liquid-hydrogen storage, methanol reforming, high-pressure hydrogen storage, lye electrolysis, petroleum reforming, and city gas reforming.

Participating vehicle manufacturers include Toyota, Nissan, Honda, DaimlerChrysler, General Motors, Mitsubishi, Suzuki, and Hino Motors, a member of the Toyota group that is testing fuel cell buses.

Energy and infrastructure companies participating include Nippon Oil Corporation; Cosmo Oil Company, Ltd.; Showa Shell Sekiyu K.K.; Tokyo Gas Co., Ltd.; Iwatani International Corporation; Japan Air Gases, Ltd.; Nippon Sanso Corporation; Nippon Steel Corporation; Kurita Water Industries, Ltd.; Sinanen Co., Ltd.; Itochu Enex Co., Ltd.; Idemitsu Kosan Co., Ltd.; and Babcock-Hitachi K.K.

Singapore

Singapore will be host to seven Mercedes-Benz NECAR fuel cell vehicles in a two-year trial beginning in 2004. Daimler expects to put 60 A-Class F-Cells on the road in four countries. DaimlerChrysler said Singapore was chosen because of the challenging climate and driving conditions, "excellent" government support, and the fact that Daimler's regional headquarters is located there.

United States

Freedom Car/Hydrogen Fuel Initiative

In his 2003 State of the Union Address, President Bush announced a new program designed to ensure that the United States become a world leader in hydrogen-powered automobiles. This program, which builds upon the President's FreedomCAR ("Cooperative Automotive Research") program, will invest a total of $1.7 billion to develop hydrogen-powered fuel cells, hydrogen infrastructure, and advanced automotive technologies, the President pledged.

Known as the FreedomCAR and Hydrogen Fuel Initiative, the President's program will partner with the private sector to make it practical to choose fuel cell vehicles by 2020. The program also will improve America's energy security by fostering the transition from petroleum fuel to hydrogen, thus reducing the demand for imported oil.

The FreedomCar and Hydrogen Fuel Initiative established teams to address advanced combustion and emission control, electrical and electronics, electrochemical storage, fuel cell systems, hydrogen storage and vehicle interface, and materials.

FreedomCar was first launched in January 2002. It is a partnership between DOE and DaimlerChrysler, Ford, and General Motors.

California Fuel Cell Partnership

The California Fuel Cell Partnership (CaFCP) is a collaboration of auto companies, fuel providers, fuel cell developers, and government agencies.[7] It was established in 1999 to demonstrate vehicle technology and alternative fuel infrastructure and to explore the path to commercialization, including increasing public awareness.

The CaFCP provides a centralized facility and other support for fuel cell vehicles being tested on California roads. The partners pool resources and work in committees to develop consensus on the partnership's major activities.

A headquarters facility in West Sacramento, California, houses vehicle maintenance bays, a hydrogen fueling station, and a methanol fueling station. Additional satellite fueling stations are in operation elsewhere in the state. The CaFCP has roughly 43 FCVs statewide and seven hydrogen fuel stations.

---

[7] Partners and associate partners include DaimlerChrysler; Ford; General Motors; Honda; Hyundai; Nissan; Toyota; Volkswagen; Ballard Power Systems; UTC Fuel Cells; BP; ExxonMobil; Shell Hydrogen; ChevronTexaco; the California Air Resources Board; the California Energy Commission; the South Coast Air Quality Management District; the U.S. Department of Energy; the U.S. Department of Transportation; the U.S. Environmental Protection Agency; Air Products and Chemicals, Inc.; Praxair; Pacific Gas & Electric; Proton Energy Systems, Inc.; Stuart Energy; ZTEK; Methanex; AC Transit; SunLine Transit Agency; and the Santa Clara Valley Transportation Authority (San Jose).

Bus Demonstrations

The U.S. government has supported research into fuel cell buses since the early 1980s. At that time, it appeared that fuel cells in transportation would need to focus on buses given their size, duty cycles, and centralized refueling and operation and maintenance. The program was led by DOE; the program produced the first U.S.-developed fuel cell buses — a fleet of three 30-foot buses on Bus Manufacturing Industries platforms. The first unit was unveiled in 1994. They were methanol-fueled hybrids utilizing phosphoric acid fuel cells. One unit has operated for nearly 10 years under a program managed by Georgetown University.

Funding shifted to the Department of Transportation in 1993. The second phase of the program focused on building two PEM hybrid buses on 40-foot Nova Bus platforms, one using a Ballard (EXCELLSIS) engine and one using a United Technologies Corporation engine. The buses were delivered in 1998 and 2001.

Georgetown University has managed the program since the beginning and is seeking funding for a third generation of buses.

The CAFCP also has a transit bus program. This program began with a Zebus provided by Ballard, which successfully completed an 18-month test at SunLine Transit Agency. The CaFCP currently plans to demonstrate seven fuel cell buses beginning in 2004. The buses will operate for two years in regular transit service, carrying fare-paying customers over normal routes. As discussed in greater detail in the bus section of this report, three buses will be deployed by AC Transit, three buses will be deployed by Santa Clara VTA, and one bus will be deployed by SunLine Transit.

Light-Duty Fuel Cell Vehicles

State of Development

Fuel Cell Vehicles (FCVs)

An international race is under way to commercialize fuel cell vehicles (FCVs). The competition is characterized by rapid technological development, early marketing activities, and governmental activism. An estimated 300 light-duty FCVs have been built and operated worldwide. The first vehicles are in the hands of carefully selected consumers, and dozens more vehicles are headed toward test fleets and multi-vehicle demonstrations in coming months.

The pace of development is all the more extraordinary when one recalls that even in the early 1990s, many automakers doubted fuel cells ever could achieve the stringent levels of power output, weight, and cost necessary to compete with internal combustion engines (ICEs). In the early 1990s, Daimler Benz quietly decided to fit a delivery van with a fuel cell and operate it on a test track. The results were announced in 1994, and the company's leaders asserted that fuel cells could lead to "sustainable mobility" within a decade or so. This stimulated an unprecedented increase in technical interest in fuel cell engines. Just as important, the unveiling prompted a series of positive statements about fuel cells from competing boardrooms. And the race was on. The first FCVs put into consumer hands were delivered by Honda and Toyota within hours of each other on December 23, 2002.

The current inventory includes concept vehicles like the General Motors HyWire and comparable visions from Toyota and DaimlerChrysler's Jeep division. These vehicles begin to expand the horizons of automotive engineering and design by taking full advantage of the characteristics and capabilities of fuel cells. But most of the vehicles on the road today reflect current marketplace expectations. Many manufacturers have made initial "down selects" to the model that will be put into early commercial use.

Manufacturers tend to share the view that fleet operations provide the best early markets. These fleets may be civilian or military. Fleets tend to provide advantages, such as central fueling and maintenance, and drivers are more easily reached for training and feedback. Fleet operators often purchase vehicles on a life-cycle cost basis rather than on first cost. Fleets often are operated by governments or companies that may wish to become early adopters for reasons of public image or private interest.

The race also has a public relations component. Image advertising is on the increase, with several companies pointing to FCVs as an expression of their corporate responsibility.

Benefits

The potential benefits of fuel cell vehicles have been discussed widely elsewhere. Benefits include fuel efficiency, unmatched emission reduction potential, fuel flexibility, and product flexibility – in design of the vehicle itself and in the potential to use the vehicle for other purposes, such as generating electricity in an emergency or power failure. It is telling that Toyota, which is regarded as the company most committed to internal combustion engine hybrid vehicles, is also among those pursuing fuel cells most aggressively. Toyota believes fuel cells will enable manufacture of a vehicle that can triple the fuel efficiency of today's vehicles — a marked improvement over hybrid drives — with extremely low or zero emissions.

For a more complete discussion of fuel cell vehicle benefits, begin at BTI's Fuel Cells 2000 website, www.fuelcells.org.

Long-Range Vision

The auto industry has begun talking openly about the long range vision of fuel cells and hydrogen.

Hiroyuki Watanabe, Senior Managing Director of Toyota, presented a sophisticated vision of the future of the automobile in 2003 at the Fuel Cell Seminar in Miami. Watanabe argued that exploding vehicle populations are a fundamental concern. He said no single technology would achieve the long-term energy efficiency and emission goals that must be achieved in the face of market expansion to remove vehicles from the pollution equation and open an era of truly sustainable mobility. But Watanabe argued that fuel cells hold the key, since they would allow fundamental redesign of vehicles, including the use of small, highly efficient wheel motors.

The FCV of the future thus could be simpler, smaller, and much lighter — perhaps 600 kilograms lighter — with no loss in customer amenities.

General Motors has promoted its Hy-Wire concept vehicle in more or less the same terms, although with more focus on the potential commercial benefits.

The Hy-Wire features handle bar controls that can be moved to either front seat.

Hydrogen

Fuel cell engines operate on hydrogen. One of the central dilemmas facing FCV commercialization is whether to generate the hydrogen off-board and store it on the vehicle or store a hydrogen-rich compound onboard the vehicle. Engineers have proven that both strategies are technically possible. Neither strategy yields a clearly preferable result — so far — from the consumer's perspective.

Storing hydrogen fuel eliminates the complexity involved in separating ("reforming") hydrogen onboard from a feedstock. But because hydrogen is a light gas, it is difficult to store enough gaseous hydrogen onboard to provide what automakers regard as an acceptable vehicle range. Storing the hydrogen at extremely low temperature in liquid form is energy-intensive and presents other issues. Hydrogen is a ubiquitous industrial gas but no consumer infrastructure exists yet, and there are cost and technology issues surrounding consumer use of hydrogen. Safety standards and product and building codes would need to be revised.

Storing the hydrogen in a feedstock (such as methanol or another liquid hydrocarbon) provides excellent range and consumers are familiar with liquid fuels. But reformers add complexity and cost, and start-up times have not achieved the speed that automakers regard as necessary for consumer satisfaction — it can take several minutes for a reformer to begin producing sufficient hydrogen from a cold start.

Hydrogen has the potential to provide worldwide energy security by providing an alternative to petroleum as a motor fuel. Hydrogen is the most abundant element in the universe. It can be produced in a sustainable manner from a variety of nonpetroleum feedstocks, including any hydrocarbon and non-carbon compounds, such as ammonia.

Perhaps the ultimate hydrogen "carrier" is plain water (H_2O). Extraction of hydrogen from water is a well known and commercial process, called electrolysis. Developers are working on efficiency and cost issues associated with the use of electrolysis to support a transportation fuel infrastructure.

Honda solar powered hydrogen fueling station.

There are several vehicle fueling stations operating today that generate hydrogen renewably and without pollution using solar power. Honda and Toyota are operating such facilities in California.

Hydrogen received a significant boost in 2001 when U.S. Energy Secretary Spencer Abraham recast the Partnership for a New Generation of Vehicles into FreedomCAR and narrowed its focus to fuel cells, hydrogen and supportive research in materials, and electric vehicle components. In effect, a U.S. government official committed the nation to examining seriously the notion that hydrogen could one day be a consumer fuel.

Challenges

Developers have tested fuel cells with varying degrees of success in nearly every conceivable passenger vehicle, from wheelchairs to military tanks, and from submarines to construction and mining equipment. The range of successful tests speaks to the flexibility and capabilities of fuel cells to provide mobile electric power. But in the case of passenger vehicles, substantial challenges remain.

Challenges in the control of the motor vehicle manufacturer include cost, performance, reliability, operation in extreme conditions, fuel choice, and the engineering challenges that flow from fuel choice.

But the greatest challenge lies at least partly outside the control of the auto manufacturer: developing a consumer infrastructure to provide the fuel, or fuels, of choice. The auto industry sees this as the area where government involvement is most crucial. While it is difficult to generalize given the broad and active development work under way, we observe the following.

1. **Size and Weight**. Engineers have made excellent progress in fuel cell size and weight. These challenges appear to be largely overcome, from the perspective of the stack itself. Passenger vehicles under test range from very small city cars to full-size SUVs.

2. **Cost**. At least one automaker has said publicly cost will not be a barrier by the time vehicles are mass produced. The industry has a superb cost reduction record.

3. **Configuration**. There appears to be a trend toward hybrid configuration: fuel cell battery in most cases, although two companies are working on fuel-cell-supercapacitor hybrids. These offer their own trade-offs in weight (batteries) and complexity. Hybrid configurations do allow for improved system efficiency with recapture of braking energy and can improve acceleration.

4. **Performance parameters**. Several companies have reported successful operation of fuel cells in extremes of heat.

5. **Durability**. Fuel cell stack lifetimes are improving, and the total number of hours in which vehicles have operated is accumulating rapidly. Research in materials and components still can pay significant dividends, however. This is one area where the demands of the application work in favor of fuel cells, since motor vehicle engines need achieve relatively short lifetimes, perhaps 3,000 hours.

6. **Hydrogen storage**. Almost all the vehicles that will be road tested in consumer hands use gaseous hydrogen, stored at pressures from about 3,200 to 5,000 psi.

7. **Fuel storage**. Companies have not abandoned the idea of using methanol or a reformulated (zero sulfur) gasoline or synfuel and reforming hydrogen onboard the vehicle. Among the companies most interested in this approach are two of the largest: Toyota and DaimlerChrysler. Companies are trying to move to 10,000 psi pressure tanks

and also are evaluating metal and chemical hydride storage, liquid hydrogen, and advanced storage options.

8. **Infrastructure.** The Japanese appear to be in the lead in addressing issues of hydrogen infrastructure, including product and safety codes governing transport and consumer use of hydrogen. There are ambitious plans in North America to develop infrastructure, however. Developing countries like China, where there is a smaller entrenched competing gasoline infrastructure, offer a different challenge but are attractive places to "leapfrog" to the fuel infrastructure of the future. Any fuel cell fuel, whether sodium borohydride, methanol or clean gasoline, will require infrastructure modifications.

Every significant automaker and many research institutions are developing and testing fuel cell vehicles. The discussion below highlights those activities.

BMW

Summary

Like its German competitors, BMW aggressively cultivates an image of environmental responsibility. BMW is pursuing Auxiliary Power Units (APUs) for its passenger cars through partnerships with United Technologies Corporation, Delphi, and Renault. The vehicles would be hydrogen-gasoline hybrids utilizing liquid rather than gaseous hydrogen as the fuel for both the APU and combustion engine. As a result, in part, of BMW's enthusiasm, other manufacturers are working with liquid hydrogen in test vehicles. BMW believes the challenge for hydrogen vehicles is as much political as technological.

Vehicles and Characteristics

BMW's **Series 7** (745h) Sedan prototype incorporates a hydrogen ICE with a United Technologies Corporation 5-kW PEM fuel cell APU fueled by liquid hydrogen. It has a range of 220 miles. The 745h is the second generation of hydrogen-powered vehicles from BMW. The first was the 750hL. BMW also showed a **Clean Mini**, with a hydrogen ICE, at the Frankfurt Auto Show in 2001.

Background

BMW dates its foundation to 1916 when a predecessor company began making aircraft engines. BMW began marketing motorcycles in 1923 and automobiles six years later. Its research and engineering center dates from the 1980s. In 1995, BMW opened a manufacturing plant in the United States. By 1998, it had acquired the rights to the Rolls-Royce and MINI names. It also briefly owned Rover. In 2002, BMW Group reported sales of more than 1 million vehicles (including about 100,000 motorcycles), and revenues of €42 billion, one-third from North America. Employment was approximately 101,000.

BMW produced an electric drive vehicle for the 1972 Munich Olympics and began experimenting with hydrogen fuel in 1979, testing a hydrogen-gasoline hybrid. In 1999, it helped finance a liquid hydrogen vehicle fueling station in Munich and unveiled the first of its 750 Series hybrids. In 2000, it began operating a fleet of fifteen 750 Series hydrogen hybrids, launching a world publicity tour in 2001.

Its relationship with Delphi, which dates from 1999, covers a variety of advanced technologies and includes solid oxide fuel cell APUs. In 2000, Renault joined the team. BMW intends to use the APUs in its passenger cars. Renault plans to use them in diesel hybrid trucks.

BMW has partnered with UTC Fuel Cells since 1999 on PEM fuel cell APUs. The 5-kW APU installed in a BMW 7 Series sedan was demonstrated at the Frankfurt Auto Show in 1999 and provided energy for all of the car's onboard electrical needs, including climate control — even when the engine was off.

Partnerships:

1. UTC Fuel Cells (1999), development of fuel cell auxiliary unit
2. Delphi (1999), development of fuel cell auxiliary unit
3. Renault (2000), development of fuel cell auxiliary unit
4. GM (2003), refueling devices

Development and Commercialization

BMW's interest in hydrogen as a consumer fuel is embodied by its "Clean Energy" concept, which it characterizes as a marriage of sustainable mobility and technological innovation. BMW plans to commercialize a hydrogen-fueled auto in its Series 7 line, hoping to mass-produce the vehicle within five years. Ten of the vehicles debuted in Los Angeles in 2001 and have toured widely. BMW believes if the infrastructure can be developed, the first commercial sales of its hydrogen vehicles will occur before 2010, with 25% market penetration sometime after 2020. BMW has engaged in serious discussions with officials about commercializing its hydrogen-gasoline hybrids in California, where a significant share of North American sales are concentrated.

BMW believes the challenge for hydrogen vehicles is as much political as technological. It has said, "The transition to a hydrogen economy involves an enormous upheaval. To provide an investment incentive, the most urgent political task is to draw up a long-term and reliable framework of conditions for introducing hydrogen onto the market."

Gallery

2001
Clean Mini

FUEL TYPE	Liquid hydrogen
ENGINE TYPE	ICE
FUEL CELL SIZE/TYPE	n/a
FUEL CELL MANUFACTURER	n/a
RANGE –	n/a
MPG EQUIVALENT –	n/a
MAX SPEED –	n/a

2000
Series 7 (745h)

FUEL TYPE	
Gasoline/liquid hydrogen	
ENGINE TYPE	
ICE (fuel cell APU)	
FUEL CELL SIZE/TYPE	
5 kW/PEM	
FUEL CELL MANUFACTURER	
UTC Fuel Cells	
RANGE – 180 mi (300 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 140 mph	

Daihatsu

Summary

Daihatsu makes small cars and four-wheeled vehicles. Most are sold in Asia. Daihatsu was a leader in electric vehicle production in Japan. Its fuel cell vehicle activities draw on its expertise as a maker of small electric "city cars." Daihatsu's current fuel cell strategy is linked to Toyota's; the two signed a formal development arrangement in 1999, and the partnership has yielded two generations of small hybrid FCVs. The current model is headed for fleet demonstration in Japan. The company says it wants to commercialize fuel cell vehicles "as soon as possible."

Vehicles and Characteristics

Daihatsu unveiled the **MOVE FCV-K-2** in 2001 at the Tokyo Auto Show. The four-passenger fuel cell mini car is powered by a 30-kW Toyota fuel cell stack, which is installed under the rear floor.

Daihatsu also played a role in developing the Toyota **FINE-S** fuel cell sports car.

Background

Daihatsu was established in 1907 as an engine manufacturer. Its first vehicles, produced in 1930, were three-wheeled. Daihatsu continues to focus on the small-vehicle market. The company adopted the Daihatsu name in 1951 and began to manufacture four-wheel vehicles in 1958. Daihatsu began collaborating with Toyota in 1967. Toyota now owns 51% of the company. More than 20 million Daihatsu vehicles have been produced. Toyota reports 2002 production of 620,000 Daihatsu vehicles. Daihatsu contributes a significant share of Toyota's sales in Japan. Daihatsu employs almost 11,000 people.

Daihatsu began work on electric vehicle technologies in 1965 and in 2000 was the largest manufacturer of EVs in Japan, with 8,000 vehicles on the road. Daihatsu began work on fuel cells in 1977 and began full-scale research in 1996, supported by a government program. The Move EV-FC, shown in 1999, is a small four-seater, with a methanol reformer and fuel cell stack developed by Daihatsu, drawing on work carried out at the Osaka National Research Institute and by MITI's Agency of Industrial Science and Technology.

After reaching agreement with Toyota in 1999, Daihatsu brought out the FCV-K-2 in 2001. It obtained government clearance for road tests early in 2003.

<u>Partnerships:</u>

1. Toyota (1999), fuel cell vehicle R&D

Development and Commercialization

Daihatsu is part of a collaborative fuel cell vehicle demonstration sponsored by the prefecture government of Osaka. Daihatsu expresses some pride in asserting the FCV-K-2 was named “the first fuel cell mini car approved for use on public roads by the Japanese Ministry.” Daihatsu will focus on the city car market in its fuel cell commercialization strategy.

Gallery

2001
MOVE FCV KII

FUEL TYPE
Compressed hydrogen @3,600 psi
ENGINE TYPE
Fuel cell battery hybrid
FUEL CELL SIZE/TYPE
30 kW/ PEM
FUEL CELL MANUFACTURER
Toyota
RANGE – 120 km (~75 miles)
MPG EQUIVALENT – n/a
MAX SPEED – 65 mph (105 km/h)

1999
MOVE EV-FC

FUEL TYPE
Methanol
ENGINE TYPE
Fuel cell/ battery hybrid
FUEL CELL SIZE/TYPE
16 kW/PEM
FUEL CELL MANUFACTURER
Daihatsu
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – n/a

DaimlerChrysler

Summary

DaimlerChrysler (DCX) believes it leads the industry in fuel cell vehicle demonstration projects worldwide. DCX is now on its fifth generation of FCVs. In 2003, it doubled its plans for demonstration automobiles to 60 vehicles. It will have 30 Citaro fuel cell buses on public roads worldwide by 2004. The company asserts that one of its vehicles was the first to provide regular service on public roads. DCX's importance to the industry goes beyond technology. Daimler Benz (DB), a predecessor company, was the first automobile manufacturer to identify fuel cell power as a serious potential competitor to internal combustion engines for passenger cars.

DCX has tested a wide variety of fuels. Methanol remains a favorite because of its relative familiarity to consumers and relatively low infrastructure costs.

DCX has embraced the concept of "sustainable mobility," and corporate leaders have said fuel cells will have a role in achieving that goal. The company also sees this as a business opportunity. Jürgen E. Schrempp, Chairman of the Board of Management, said in 2003, "We're aiming for market leadership in this sector as well."

Vehicles and Characteristics

NECAR is the company's line of fuel cell passenger vehicles. The NECAR 5, designed in 2000, carries the entire fuel cell in the underbody of the Mercedes Benz A-Class sedan. It can hold up to five people with luggage and achieve speeds of 90 mph. NECAR 5 is a pre-production prototype "fit for practical use," and in 2004 it is possible a significant number of units will be introduced.

The **F-Cell** was developed in 2002 and is being used in a Japanese testing facility subsidized by the government. It is also a Mercedes Benz A-Class car with a top speed of nearly 90 mph. It uses compressed hydrogen and has a range of 93 miles.

The **Sprinter Van**, which debuted in 2001, will soon be incorporated into experimental service with UPS; it runs on gaseous hydrogen. It can reach speeds of 75 mph and has a range of 93 miles.

DCX is also developing a prototype for a single-person fuel cell vehicle, the **Jeep Treo**, shown in Japan in 2003.

Background

Gottlieb Daimler and Karl Benz were both improving the combustion engine in the late 1800s. Although Daimler and Benz never met, their corporations — Daimler Motoren Gesellschaft and Benz and Company — merged in 1926 to form Daimler Benz. During World War II, the company expanded to produce military products, and it further diversified in the 1980s when faced with Japanese automotive competition.

Walter Chrysler left General Motors in 1920 to join Maxwell Motor Corporation, which became the Chrysler Corporation five years later. In 1928, Chrysler bought out the Dodge Brothers Company.

In 1998, Daimler Benz AG merged with the Chrysler Corp. to form DaimlerChrysler in one of the largest merges in history. Daimler Benz's quality combined with Chrysler's low-cost manufacturing. Its passenger car brands include Maybach, Mercedes-Benz, Chrysler, Jeep®, Dodge, and Smart. Commercial vehicle brands include Mercedes-Benz, Freightliner, Sterling, Western Star, and Setra.

DCX also produces aircraft and aircraft engines, satellites, space systems, guided missile weapons systems, trains, electronics, and home appliances. DCX sold 4 million vehicles in 2002 and reported revenues of €149.6 billion and employment of 365,000 workers.

Daimler Benz (DB) began a serious assessment of fuel cell technologies in 1990, as part of an evaluation of hydrogen as a fuel and a board-level assessment of alternatives to conventional internal combustion engines and gasoline. DB unveiled its first fuel cell vehicle, NECAR 1 (New Electric Car), in 1994. A delivery van was fitted to operate on a 50-kW Ballard fuel cell fueled by compressed hydrogen and driven approximately 2,000 km before its unveiling.

Performance of the NECAR 1 convinced the company that fuel cells deserved a serious research investment. DB set up a separate research facility in 1996, called Fuel Cell House, and focused initially on methanol as the hydrogen carrier. Later research vehicles were used to test a variety of fuels and configurations.

In 1997, DB took a 25% equity stake in Ballard Power Systems and a 67% stake in a joint venture with Ballard called Daimler Benz-Ballard Fuel Cell Engines, which helped launch Ballard's successful run of equity financing. Ford joined the partnership in 1998, bringing its drive train technology to the collaboration. Together, the partners formed XCELLSIS, to manufacture vehicle engines, and Ecostar, to focus on Ford's electric drive train and power electronics capability.

DB's market projections for fuel cell vehicles helped stimulate unprecedented interest in the technology. DB raised the prospect of commercial-scale production of fuel cell vehicles (50,000 to 100,000) by 2004–2005. The projections proved optimistic, however, and DB in recent years has conceded the public relations spotlight to others.

DB's relationship with Ballard helped stimulate an active fuel cell bus development program, initially aimed at a multi-unit demonstration in California as part of the California Fuel Cell Partnership.

When DB merged with Chrysler in 1998 to become DaimlerChrysler (DCX), managers steered Chrysler's fuel cell program away from gasoline. Following the merger, DCX refocused its own fuel cell program, informing California officials it would not provide buses for California demonstrations, renegotiating its arrangements with Ballard (see below) and concentrating research in Germany.

The resources of XCELLSIS and Ecostar were acquired by Ballard in November 2001. A Ballard news release at the time disclosed that, in return, the auto companies agreed to a 20-year commitment to rely on Ballard engine technology. Most of the transfer was accomplished via stock issue, but the auto companies agreed to invest an additional $69 million in return for a modest increase in their ownership stake in Ballard. By mid-2003, XCELLSIS and Ecostar had ceased to exist as separate entities, and assets were either transferred to Germany or consolidated at Ballard.

Chrysler's Fuel Cell Vehicle Program was relatively modest pre merger, compared with Daimler's. Most pre-merger activity was undertaken in the context of the Partnership for a New Generation of Vehicles (PNGV), funded largely by the U.S. federal government. Chrysler's focus was on a PEM fuel cell hybrid proof of concept, aimed at operation on gasoline (or a comparable liquid hydrocarbon). Chrysler unveiled a fuel cell hybrid version of its Jeep Commander in 1999, operating on methanol. A second Commander was unveiled in 2000. Chrysler purchased all the major components from vendors, and Ballard supplied the PEM fuel cell stack.

Chrysler's focus on liquid hydrocarbons ended with the merger with Daimler. In 2001, Chrysler unveiled the Natrium, a Town and Country minivan converted to a fuel cell battery hybrid configuration, operating on sodium borohydride (essentially a hydrated soap). This vehicle has received considerable attention as an example of the alternatives to conventional fuel made possible by fuel cells.

Partnerships:

1. Mitsubishi (1998), fuel cell power systems
2. Mazda (1998), fuel cell research and development
3. Volvo
4. Ford, development and testing of fuel cell technology

Development and Commercialization

DaimlerChrysler operates several demonstrations worldwide. These demonstrations are part of the first phase of DCX's commercialization strategy: the "market preparation" phase. The second step, called "fit for daily use," is expected to cover 2004 through 2007. DCX plans to place 100 more fuel cell vehicles on roads in the United States, Europe, and Asia, including cars, Citaro buses, and Sprinter vans. The third segment is "ramp up," and the fourth stage, starting about 2010, is full commercialization.

In 2004, United Parcel Service (UPS) will operate a small fleet of Sprinter vans in Michigan. Hermes delivery service in Germany has placed the first FCV in regular service on public roads. DaimlerChrysler said recently it will deliver a total of 60 small fuel cell vehicles known as "F-Cells" in Japan, Germany, the United States, and Singapore through 2004 to such entities as the U.S. Environmental Protection Agency, Tokyo Gas Co. Ltd., and Japanese tire maker Bridgestone Corp. This represents an acceleration compared to earlier announcements.

DCX fuel cell buses are being demonstrated in Australia, Iceland, and seven countries in continental Europe.

NECAR 5 took a publicized trip from San Francisco to Washington, D.C.; that was the first attempt to drive an FCV more than 3,000 miles.

DCX is a partner, often the leading commercial partner, in a variety of automobile and bus demonstrations.

The world's first fleet of commercial fuel cell buses consists of 30 Mercedes Benz **Citaro** buses that will be entered into revenue service in 10 European cities as part of the Clean Urban Transport for Europe (CUTE) project. The first bus was delivered to the Mayor of Madrid, and three have been delivered to London and Amsterdam. DCX is also involved in:

- ECTOS, the three-bus project in Iceland, partially financed by the European Union; the program will run through 2005;
- The California Fuel Cell Partnership; DCX was a founding member;
- The FreedomCAR program, a research program in loose collaboration with Ford, GM, and the DOE; and
- The Clean Energy Partnership Berlin with the German Ministry of Traffic and Aral, BMW, Berlin Transport, Ford, Linde, MAN, and Opel; they will operate a test fleet of 30 vehicles using hydrogen generated by electrolysis.

Gallery

2003
Jeep Treo (concept vehicle)

FUEL TYPE	Hydrogen
ENGINE TYPE	Fuel cell
FUEL CELL SIZE/TYPE	n/a
FUEL CELL MANUFACTURER	n/a
RANGE –	n/a
MPG EQUIVALENT –	n/a
MAX SPEED –	n/a

2002
F-Cell A-class

FUEL TYPE	Compress. H_2 @ 5,000 psi
ENGINE TYPE	Fuel cell/ battery hybrid
FUEL CELL SIZE / TYPE	85 kW/PEM
FUEL CELL MANUFACTURER	Ballard Mark 900 Series
RANGE –	90 mi (145 km)
MPG EQUIVALENT –	56 mpg
MAX SPEED –	87 mph (140 km/h)

2001
Natrium (Town & Country Minivan)

FUEL TYPE	Catalyzed chemical hydride – sodium borohydride
ENGINE TYPE	Fuel cell/battery hybrid
FUEL CELL SIZE / TYPE	54 kW/PEM
FUEL CELL MANUFACTURER	Ballard Mark 900 Series
RANGE –	300 mi (483 km)
MPG EQUIVALENT –	30 mpg
MAX SPEED –	80 mph (129 km/h)

2001
Sprinter (van)

FUEL TYPE	
Compress. H_2 @ 5,000 psi	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
85 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard Mark 900 series	
RANGE – 93 mi (150 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 75 mph (120 km/h)	

2001
NECAR 5.2 (A-class)

FUEL TYPE	
Methanol	
ENGINE TYPE	
Fuel cell/battery hybrid	
FUEL CELL SIZE/TYPE	
85 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard Mark 900 series	
RANGE – 300 mi (482 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 95 mph (150 km/h)	

2000
DMFC Go-cart (one-person vehicle)

FUEL TYPE	
Methanol (directly)	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
3 kW/ DMFC	
FUEL CELL MANUFACTURER	
Ballard Mark 900 series	
RANGE – 9.3mi (15 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 22 mph (35 km/h)	

2000
NECAR 5 (A-class)

FUEL TYPE	
Methanol	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
85 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard Mark 900 series	
RANGE – 280 mi (482 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 95 mph (150 km/h)	

2000
NECAR 4 Advanced (California)

FUEL TYPE	
Compress. H_2 @ 5,000 psi	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
85 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard Mark 900 series	
RANGE – 124 mi (482 km)	
MPG EQUIVALENT – 53.46 mpg (CaFCP est.)	
MAX SPEED – 90 mph (140 km/h)	

2000
Jeep Commander 2 (Jeep Commander 1 came out in 1999)

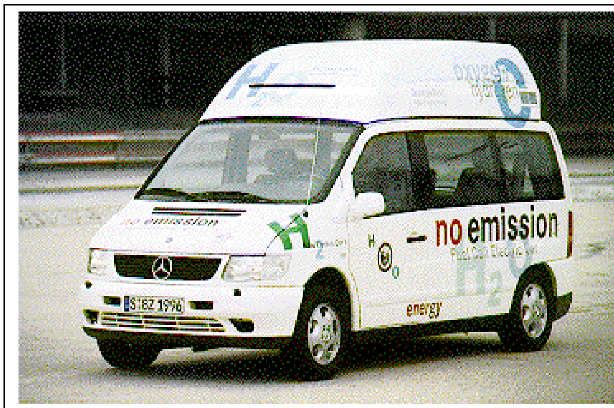
FUEL TYPE	
Methanol	
ENGINE TYPE	
Fuel cell/battery hybrid	
FUEL CELL SIZE/TYPE	
50 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard Mark 700 series	
RANGE – 118 mi (190 km)	
MPG EQUIVALENT – 24 mpg	
MAX SPEED – n/a	

1999
NECAR 4 (A-class)

FUEL TYPE
Liquid hydrogen
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
70 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 900 series
RANGE – 280 mi (450 km)
MPG EQUIVALENT – n/a
MAX SPEED – 90 mph (145 km/h)

1997
NECAR 3 (A-class)

FUEL TYPE
Liquid methanol
ENGINE TYPE
2 fuel cell stacks
FUEL CELL SIZE/TYPE
50 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 700 series
RANGE – 250 mi (400 km)
MPG EQUIVALENT – n/a
MAX SPEED – 75 mph (120 km/h)



1996
NECAR 2 (V-class)

FUEL TYPE
Compress. H_2 @ 3,600 psi
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
50 kW/PEM
FUEL CELL MANUFACTURER
Ballard
RANGE – 155 mi (400 km)
MPG EQUIVALENT – n/a
MAX SPEED – 68 mph (110 km/h)

1994
NECAR 1 (180 van)

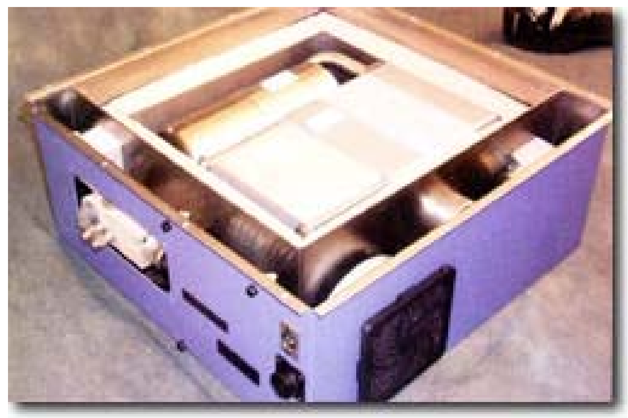
FUEL TYPE	
Compress. H_2 @ 4,300 psi	
ENGINE TYPE	
12 fuel cell stacks	
FUEL CELL SIZE/TYPE	
50 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard	
RANGE – 81 mi (130 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 56 mph (90 km/h)	

Delphi

Summary

Delphi has been a leader in mobile electronics, transportation components, and systems technology for more than 100 years. Delphi is concentrating fuel cell research and development efforts on Solid Oxide Fuel Cells (SOFCs) for cars, trucks, military applications, and stationary power units. Delphi CEO and President J.T. Battenberg III stated that Delphi is "a strong proponent of advanced fuel cell development."

Products and Characteristics



Delphi's goal is a SOFC that will supply up to 6 kW of power, which is enough to run heating, air conditioning, navigation systems, mobile offices, sound systems, heated seats, telecommunications, and more without the need for engine or battery power. Delphi unveiled a unit in 2003 that weighs 70 kilograms and displaces 44 liters of volume. In September 2003, Delphi demonstrated a unit operating on gas derived from coal.

Background

Delphi is the largest supplier of transportation technology in the world, with annual sales of $27.4 billion. Delphi was first to create a self-starting engine and first to develop a catalytic converter. Delphi employs 201,000 people worldwide, 16,000 of whom are engineers. The headquarters are in Troy, Michigan; Delphi has offices in 37 countries, including main offices in Paris, Tokyo, and Sao Paulo.

Delphi has been working on fuel cells for the past 10 years, supported by DOE. In the late 1990s, Delphi worked with Ballard and Chrysler to supply a PEM fuel cell for a Chrysler FCV concept. Delphi and its partner, Battelle, have been working since 2001 with DOE on a $138 million, 10-year project to develop and test SOFC auxiliary power units that can be mass produced at low cost.

Partnerships:

1. Peugeot (1999), fuel cell research
2. BMW (2000), cleaner gasoline development project and SOFC technology
3. Renault (2000), cleaner diesel fuel and SOFC technology
4. TotalFinaElf (2001), research and testing of fuel cells in reformers
5. French Ministry of Research (2001), fuel cell research
6. Battelle (2001), development of SOFC technology
7. Belfort Fuel Cell Research Center, technical research

Development and Commercialization

Early in 2003, Delphi unveiled a 5-kW SOFC unit that it says represents a 75% reduction in mass and volume compared to the first generation unit. The new unit would not only be easier to use, but it also ought to be much cheaper to manufacture.

Delphi believes it has made significant progress in pursuit of a commercial market for fuel cell APUs. Its marketing strategy may be reflected in the comments of Guy C. Hachey, president of Delphi Energy Chassis Systems: "On passenger vehicles, it can power a vehicle's heating, ventilation and air conditioning system, as well as other accessories, so a smaller combustion engine can be used to propel it. For the military, the technology can be used to help power combat and security vehicles. On semi trucks, it can be used to power air conditioning, heater, TV, radio, computer and other electronic devices during the drivers' rest periods to reduce the burning of diesel fuel, which will cut emissions. For homes and offices, solid oxide fuel cells can be used to generate electric power."

Fiat

Summary

Fiat has been making cars for more than a century. It has significant experience in electric vehicles and in innovative commercial strategies. Fiat's interest in fuel cell vehicles is tied to its innovative small car programs and will be influenced by the direction of Italian government policy. Fiat has given a fuel cell car to the mayor of Torino and one to a senior aide to the environmental councilor.

Vehicles and Characteristics

The four-passenger **Seicento Elettra** uses compressed hydrogen. Fiat claims its Seicento Elettra is the smallest fuel cell vehicle ever built, underscoring Fiat's desire to produce city cars.

In October 2003, Fiat introduced its third generation of fuel cell compact cars, an updated **Seicento/600** and the **Panda Hydrogen,** which also utilize earlier EV technology.
Both use Nuvera Andromeda fuel cells. Fiat claims the new Panda provides passenger room and operating characteristics comparable with those of the conventionally powered version.

Background

Fiat was established in 1900 in Torino (Turin), Italy, and went international by setting up Fiat Automobile Co. in the United States in 1908. Today, Fiat employs 223,000 workers in 61 countries. It recorded sales of €57 billion in 2003. The group produces about 2.5 million passenger vehicles a year. Fiat also produces trucks, steel, agricultural machines, marine engines, aviation equipment, and aerospace technology. Fiat merged in 1979 with Lancia, Autobianchi, Abarrth, and Ferrari to form Fiat SpA. In 1986, the group added Alfa Romeo and Maserati. Fiat also owns Irisbus, which has developed a prototype fuel cell bus. Fiat is 20% owned by General Motors.

Fiat has focused on small cars and affordable specialty cars since the late 1940s. Fiat produced a few EV prototypes in the 1970s, made and sold a few vans in the 1980s, and by 1990 was producing a 22-passenger electric minibus and had announced production of the Panda Elettra. Its fuel cell vehicle line starts with the Seicento Elettra, which began trials in four European cities in 1999. The Seicento is based on the Fiat 600.

Fiat unveiled its first prototype fuel cell vehicle, the Seicento Elettra H2, a hybrid powered by a Nuvera Fuel Cells fuel cell system, in February 2001. This was a project sponsored by the Italian Environmental Ministry. Two more vehicle generations followed.

<ins>Partnerships:</ins>

1. GM (2000), automotive research and manufacturing
2. Nuvera (2003), fuel cell technology

Development and Commercialization

Fiat's fuel cell passenger vehicle strategy is likely to parallel its electric vehicle strategy, which is seeking premium early markets, government support, and innovative approaches (such as "station cars"), as well as focusing on the city car market. Fiat is developing a small FCV by using Nuvera fuel cell stacks for community vehicles in Milan, Italy. (Diesel and gas vehicles are banned on certain days considered too smoggy in Italy.) Fiat states, however, that the car is still a long way from commercialization.

Fiat has given a fuel cell car to the mayor of Torino and one to a senior aide to the environmental counselor.

Gallery

2003
Panda Hydrogen (production concept)

FUEL TYPE	Compressed hydrogen
ENGINE TYPE	Hydrogen internal combustion
FUEL CELL SIZE/TYPE	n/a
FUEL CELL MANUFACTURER	Nuvera
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

2003
Seicento Elettra H2 Fuel Cell

FUEL TYPE	Compressed hydrogen
ENGINE TYPE	Fuel cell/ battery hybrid
FUEL CELL SIZE/TYPE	40 kW/PEM
FUEL CELL MANUFACTURER	Nuvera
RANGE – ~220 km	
MPG EQUIVALENT – n/a	
MAX SPEED – 130 km/h	

2001
Seicento Elettra H2 Fuel Cell

FUEL TYPE	
Compressed hydrogen	
ENGINE TYPE	
Fuel cell/ battery hybrid	
FUEL CELL SIZE/TYPE	
75 kW/ PEM	
FUEL CELL MANUFACTURER	
Nuvera	
RANGE – 100 mi (140 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 100 km/h	

Ford

Summary

Ford is one of the largest auto manufacturing companies in the world and has an explicit commitment to creating vehicles that operate on alternative fuels. Its fuel cell program, while not the first among U.S. automakers, is among the most ambitious. Ford is co-owner with DaimlerChrysler of Ballard, and its recent fuel cell development history is linked to that relationship. Despite the recent economic slump, Ford apparently remains committed to bringing a fuel cell vehicle to market. Low-level production of fuel cell hybrid passenger vehicles to support fleet sales is expected in 2004; vehicles available for mass public consumption are projected to be available by 2010. The Chairman of Ford, William Clay Ford, has said he believes the fuel cell will revolutionize the industry just as the Model T did.

Vehicles and Characteristics

The **P2000** is Ford's fuel cell sedan; it is similar to the Taurus. It has a top speed of 80 mph and a range of 100 miles. It is powered by a Ballard Power Systems proton exchange membrane (PEM) fuel cell. A P2000 SUV is in development as well.

Ford is experimenting with several varieties of fuel cell power and has based its line of cars on its popular compact **Focus**. The standard fuel cell vehicle is the **Focus FCV**; the Ford **Focus FCV Hybrid** combines a Nickel-Metal Hydride voltage battery with hydrogen-powered engine; the **Focus FC5** is powered by a methanol reformer fuel cell system and electric motor. Fleet sales are scheduled to begin in 2004.

The Model U features a 2.3-liter, four-cylinder supercharged, intercooled hydrogen internal combustion engine, coupled with a hybrid electric transmission. It gets about 45 mpg equivalent and has a range of about 300 miles, with "near-zero" emissions. Ford believes the hydrogen ICE can provide a stepping stone to hydrogen-powered FCVs.

Background

Ford Motor Company was incorporated in 1903 and its first vehicle, the Model A, was shipped a month later. As a result of founder Henry Ford's innovative vision of creating cars for the masses, Ford Motor Co. was turning a profit within months. By implementing the assembly line, Ford revolutionized the industry and made production more efficient. In 1922, Ford acquired Lincoln Motor Company and produced its first luxury vehicle.

The Mercury line of cars was created in the 1930s, the only vehicle line created from within Ford, to fill the gap between the luxurious Lincolns and the economical Fords. In 1989, Ford bought Jaguar; five years, later Ford purchased Aston Martin. In 1996, Ford acquired a 33.4% stake in Mazda Motors. In 1999, Ford bought Volvo, and the following year, BMW sold them Land Rover. The company reported $162 billion in revenues and sales of 7 million vehicles. The company employs 350,000 persons, including 162,000 in the United States.

Ford has been active in alternative fuel and alternative power train vehicles at least since the 1980s. Its methanol dual-fuel vehicles were highly regarded, and it has offered electric vehicles, propane-powered vehicles, and compressed natural gas vehicles to consumers. It also offers two models that use both ethanol and gasoline.

Ford developed highly regarded electric drive train and power electronics technology and brought that technology to the Ballard-DaimlerChrysler partnership in 1998.

Ford's current fuel cell program dates back to the early 1990s. As a partner in the Partnership for a New Generation of Vehicles (PNGV), Ford achieved significant research results under a contract initiated in 1994. Working with then-International Fuel Cells (now UTC), Ford delivered a 50-kW hydrogen fuel cell engine operating without an air compressor. Ford remains a partner with the U.S. government in the FreedomCAR program. Ford has used Ballard stacks exclusively since acquiring a stake in Ballard.

The first operating Ford FCV was a P2000 model shown in 1999 as a PNGV deliverable. Ford shifted platforms to the Focus in 2000 and has shown three generations of Focus — most recently a fuel cell-battery hybrid that claims a 200 mile range.

For a time, Ford's fuel cell research was integrated with the TH!NK electric vehicle program. When TH!NK was abandoned in the United States in 2002, Ford retained its fuel cell research program as a product development activity.

Mazda's Fuel Cell Vehicle Program also dates from the mid-1990s. A fuel cell version of Mazda's Demio compact was shown in 1997, utilizing a stack developed in-house. Two Premacy fuel cell models (one a hybrid) released in 2001 show the impact of the collaboration with Ford and feature Ballard fuel cell engines. (See separate section on Mazda.)

<u>Partnerships</u>:

1. Mazda (1998), fuel cell research and development
2. Ballard (1999), development and testing of fuel cell technology
3. BPAmoco (2000), cleaner fuels
4. Chrysler, development and testing of fuel cell technology
5. ExxonMobil, exploration of onboard fuels
6. Volvo

Development and Commercialization

Ford is a member of the FreedomCAR Partnership. Ford also joined with Fuel Cells Canada and the Canadian and British Columbian governments in the Vancouver Fuel Cell Vehicle Project. It is a three-year, CAN$5.8 million project that will test different FCVs throughout the city.

Ford has said it hopes to sell 50,000 FCVs by 2010, a goal unlikely to be achieved given the current state of development. Ford anticipated placing its first test fleets on U.S. roads in 2004, a slight slippage from the 2003 target announced earlier.

No plans have been announced publicly to commercialize the Model U, but the release of the new Mazda hydrogen combustion vehicle must be considered significant.

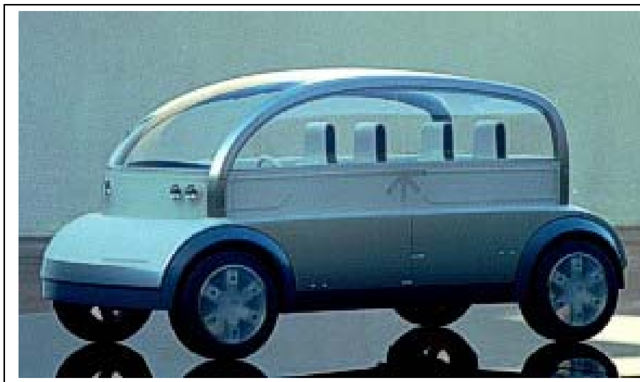
Hydrogen Combustion

Ford and Mazda are leaders in hydrogen combustion engine technology.

In 2003, Ford unveiled its Model U, a battery-combustion engine hybrid that uses hydrogen fuel. This vehicle has been received enthusiastically by advocates of hydrogen combustion as a "bridge" strategy to stimulate a hydrogen fuel infrastructure.

Mazda began working on hydrogen combustion engines much earlier and, between 1991 and 1995, showed four vehicles, including a station wagon, operating on hydrogen rotary engines. In 2003, Mazda unveiled a new generation of hydrogen combustion vehicle, utilizing a direct injection rotary engine and an RX-8 body. The engine is called the RENESIS. The vehicle is capable of operating on hydrogen (stored as a gas under pressure) or on gasoline.

Gallery



2003
GloCar (Concept Only)

FUEL TYPE
n/a
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
n/a
FUEL CELL MANUFACTURER
n/a
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – n/a

2002
Advanced Focus FCV

FUEL TYPE
Compress. H_2 @5,000 psi
ENGINE TYPE
Fuel cell/ battery hybrid
FUEL CELL SIZE/TYPE
85 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 900 Series
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – 80 mph

2000
Th!nk FC5

FUEL TYPE
Methanol
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
85 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 900 Series
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – 80 mph (128 km/h)

2000
Focus FCV

FUEL TYPE
Compress. H_2 @ 3,600 psi
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
85 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 900 Series
RANGE – 100 mi (160 km)
MPG EQUIVALENT – n/a
MAX SPEED – 80 mph (128 km/h)

P2000 HFC
1999

FUEL TYPE
Compress. H_2
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
75 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 900 Series
RANGE – 100 mi (160 km)
MPG EQUIVALENT – 67 mpg
MAX SPEED – n/a

General Motors

Summary

In the past decade, General Motors (GM) has moved from skeptic to committed advocate of fuel cells for passenger vehicles. Officials have said it is GM's goal to be the first company to sell one million fuel cell vehicles at a profit. Prompted in part by the early success of Daimler Benz, GM built a test vehicle in Europe at its Opel subsidiary and gradually increased its research activity worldwide. GM officials are highly visible in discussing the company's work and commercialization plans and have said that the U.S. government's timetable for commercialization is unnecessarily cautious. GM says it expects to have "significant numbers" of fuel cell vehicles in customers' hands by the end of this decade. Aggressive cost targets (~$50 kW) are also achievable, the company says.

GM's leadership is especially evident in its announced intention to commercialize 50-kW fuel cell generators within the next two years, as part of a cost-reduction strategy. GM also helped shape the auto industry's approach to fuel cell vehicles by unveiling the AUTOnomy concept in 2002 and by building a drivable proof of concept, the HyWire. The vehicle combines "by wire" guidance technology with the design flexibility offered by fuel cells. The result is a long lifetime "skateboard" just 11 inches high, upon which a consumer could fit the vehicle body of his choice. Two other automakers have since shown similar concepts.

General Motors has 500 employees working on fuel cells in the United States and Europe. "Fuel cells are very important to GM's future. We've spent hundreds of millions already and we're going to spend a lot more than that until we get into production vehicles," stated GM chief executive officer Rick Wagoner.

Vehicles and Characteristics

General Motors has produced multiple fuel cell vehicle lines over the past five years. Its **Zafira** minivan can fit five people, achieve a top speed of 87 mph, and travel 250 miles. It uses a 50-kW PEM Ballard fuel cell. It has come a long way since its debut in 1998.

The van line, the **HydroGen 1, 2** and most recently **HydroGen 3** (2002), has become lighter and faster with increasing range and more powerful fuel cell engines.

In 2000, GM developed the **Precept**, a four-wheel-drive five-person sedan. The Precept features a 100-kW GM fuel cell. It has an estimated range of 500 miles and a top speed of 120 mph.

In 2002, GM unveiled a concept car, the **AUTOnomy,** that it says has opened new engineering pathways for the fuel cell vehicle industry. The AUTOnomy combines a by-wire navigation system, fuel cell engine technology, and electric motors in a long-lifetime chassis.

The AUTOnomy concept features virtually no moving parts — no engine, no transmission, and no steering wheel. The car would be silent, with quick acceleration and no emissions other than pure water. Its fuel cell could generate enough surplus electricity to run a home.

GM built a drivable version of the AUTOnomy and renamed it the **HyWire**. The car was named for its combination of hydrogen fuel cell and drive-by-wire technology. The fuel cell, motors, and controllers are all carried in an 11-inch thick skateboard-like chassis. The body of the car can be selected separately — from a sports car to a minivan — as the driver's needs or desires change.

The HyWire has traveled extensively and created strong interest wherever it has gone. Other carmakers are developing comparable concepts, and there certainly will be more innovation as auto engineers begin to take full advantage of the fuel cell.

GM is also developing a diesel hybrid **Military Truck** with a fuel cell APU, which is currently under military evaluation. The U.S. Army plans to develop a new fleet of 30,000 trucks by the end of the decade.

Background

General Motors is the world's largest vehicle manufacturer. In 2002, GM sold more than 8.6 million cars and trucks, which represents nearly 15% of the global vehicle market. GM employs 340,000 people in 32 countries, with headquarters in Detroit. Its vehicles are sold in more than 190 countries.

GM traces its history to the founding of Oldsmobile in 1897. GM itself was organized in 1908. By 1920, most of the brands now known as GM brands had been brought together; in that year, GM founded a research division.

GM's strategic relationships and equity stakes extend to Japan, Korea, China, Europe, and many other countries.

GM has had an interest in fuel cells for 40 years. It conducted its first fuel cell testing in 1964. In 1968, GM unveiled the Electrovan, the auto industry's first fuel cell vehicle. (Allis Chalmers built and operated a fuel cell tractor in 1959.) The Electrovan utilized liquid hydrogen and liquid oxygen. The concept was set aside in the 1970s, and work moved into the laboratory.

In the mid-1990s, GM participated in the PNGV, initiating a stack development project with Giner, Inc., in 1995. In 2000, this collaboration led to a joint venture called Giner Electrochemical Systems. GM's strategy is to develop partnerships with major suppliers and collaborators (see list), but its fuel cell engines are GM products.

GM's view in the 1990s favored gasoline as a feedstock fuel, with onboard reforming. It signed a research agreement with Exxon and Arco in 1996. It has signed research agreements with ExxonMobil, BP Amoco, and ChevronTexaco, and it has signed an agreement on hydrogen supply with Shell Hydrogen. The company released a working S-10 pickup in 2002 that featured a GM gasoline reformer. This was regarded as a significant feat of engineering. Long start-up times continue to pose questions about the commercial readiness of onboard reformers, however.

GM showed a fuel-cell-powered Opel in 1997, unveiling a working version in 1998 that it calls the first drivable fuel cell passenger car.

The year 2000 was busy for GM. The Precept, GM's PNGV offering, was delivered early in the year. GM said it would achieve 108 miles per gallon (equivalent). The HydroGen 1, based on Opel's Zafira van, was released in September and immediately went on tour in Asia.

In 2001, the S-10 was shown; a drivable version was released a few months later, in 2002. GM also released the HydroGen 3 in Europe, which showed remarkable improvement over the 1998 model.

Recent Activities

The fuel cell vehicle universe changed dramatically in 2001. Just as DOE was recasting PNGV into FreedomCAR and increasing the focus on hydrogen as a potential consumer fuel, GM unveiled the AUTOnomy concept, followed a few months later by the HyWire test vehicle. With their wheel motors, "skateboard" architecture, and reliance on electronic guidance systems, the vehicles gave a hint of what auto engineers might be able to achieve if they took full advantage of the capabilities of the fuel cell and other technology advances to break free from conventional vehicle architecture.

The impact on the industry is nearly as significant as was Daimler Benz's initial unveiling of the NECAR 1.

GM showed the Phoenix vehicle, produced by its Chinese partner, in 2002 (see separate listing), along with an advanced HydroGen 3, the first vehicle to utilize high-pressure hydrogen storage tanks.

GM has settled on the HydroGen 3 for its initial fleet demonstrations and, in 2003, announced fleet demonstrations in Washington, D.C., and in Japan, with Federal Express.

GM dedicated its Fuel Cell Development Center in Honeoye Falls, New York, in 2002; this facility will develop fuel cell technology for commercial use. The facility has about 300 staff; 200 GM employees are working on fuel cells in Europe and the United States.

Other Programs

GM is pursuing specialty power markets in collaboration with Hydrogenics and hopes to market 50–70-kW distributed power units within a year or two. The first installations will be in Texas, under an agreement reached with Dow Chemical that could result in installation of 500 units.

In 2003, GM unveiled a fuel cell APU developed for U.S. Army vehicles.

Partnerships:

1. Toyota (1999), advanced fuel cell research
2. Fiat (2000), automotive research and manufacturing
3. Giner Electrochemical Systems (2000), refueling systems and stationary power technologies
4. Suzuki (2001), small fuel-cell-vehicle development
5. ChevronTexaco (2001), fuels research
6. Quantum Technologies (2001), onboard hydrogen storage
7. General Hydrogen (2001), hydrogen infrastructure technologies
8. Hydrogenics (2001), fuel cell back-up power product development
9. Gillig (2001), electric hybrid power
10. ExxonMobil (2001), fuel and reformer research
11. BMW (2003), refueling devices

Development and Commercialization

GM plans to establish high-volume fuel cell production before 2010. GM is looking to sell hundreds of thousands of fuel cells and FCVs by 2020 by entering power generation markets first. GM has teamed with many other companies in pursuit of this goal. Partners include Shell, Toyota, BMW, Suzuki, ExxonMobil, and many others.

GM is part of the FreedomCAR project, the DOE-led research partnership that also includes Ford and DaimlerChrysler.

GM is demonstrating the HydroGen 3 for a year through FedEx in Tokyo and has placed a six-car fleet in Washington, D.C.

Distributed Generation

GM is also focused on fuel cell generator sets, believing fuel cells will be marketed for stationary applications before they are widely available in vehicles. "Fuel cells are an emerging technology, with the potential for widespread application," said Vice President Larry Burns. "We're doing some cutting-edge research in this area, and it only makes sense to use what we're learning in ways that provide the greatest benefit to our customers, communities and shareholders."

GM unveiled a fuel cell generator in early 2002. A GM prototype stationary fuel cell unit already generates power at GM's New York fuel cell center, and there are plans to supply a Dow Chemical plant in Texas with systems (which could lead to them purchasing as many as 500 fuel cells).

This chart illustrates how GM believes distributed generation development will serve existing needs now, while building toward vehicle fuel cell development by facilitating cost reduction.

GM is also hoping for a global market expansion. Currently, only 12% of the world's population owns a car. With vehicles such as AUTOnomy costing significantly less, GM hopes to break into the markets of such places as Brazil, Mexico, India, and especially China, which has no established gasoline network and a desire for low- or zero-emission vehicles. GM has plans to open a plant in China and recently called on Chinese officials to "leapfrog" a gasoline infrastructure in favor of hydrogen. (See discussion below.)

Gallery

FUEL TYPE
Low-pressure metal hydrides
ENGINE TYPE
Fuel cell APU
FUEL CELL SIZE/TYPE
5 kW/PEM
FUEL CELL MANUFACTURER
Hydrogenics
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – 44 mph (70 km/h)

2003
Diesel Hybrid Electric Military Truck (w/fuel cell APU)

FUEL TYPE
Compress. H_2 @ 10,000 psi
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
94 kW/PEM
FUEL CELL MANUFACTURER
GM/Hydrogenics
RANGE – 170 mi (270 km)
MPG EQUIVALENT – ~55 mpg
MAX SPEED – ~100 mph (160 km/h)

2002
Advanced HydroGen 3 (Zafira van)

FUEL TYPE
Compress. H_2 @ 5,000 psi
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
94 kW/PEM
FUEL CELL MANUFACTURER
GM/Hydrogenics
RANGE – 80 mi (129 km)
MPG EQUIVALENT – ~41 mpg
MAX SPEED – 97 mph (160 km/h)

2002
Hy-Wire (proof of concept)

2002
AUTOnomy (concept only)

FUEL TYPE	n/a
ENGINE TYPE	Fuel cell
FUEL CELL SIZE/TYPE	n/a
FUEL CELL MANUFACTURER	n/a
RANGE – n/a	
MPG EQUIVALENT – projected 100 mpg	
MAX SPEED – n/a	

2001
Chevy S-10 (pickup truck)

FUEL TYPE	Low-sulfur, clean gasoline (CHF)
ENGINE TYPE	Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE	25 kW/PEM
FUEL CELL MANUFACTURER	GM/Hydrogenics
RANGE – 240 mi (386 km)	
MPG EQUIVALENT – 40 mpg	
MAX SPEED – 70 mph	

2001
HydroGen 3 (Zafira van)

FUEL TYPE	Liquid hydrogen
ENGINE TYPE	Fuel cell
FUEL CELL SIZE/TYPE	94 kW/PEM
FUEL CELL MANUFACTURER	GM/Hydrogenics
RANGE – 250 mi (400 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 100 mph (160 km/h)	

2000
HydroGen 1 (Zafira van)

FUEL TYPE
Liquid hydrogen
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
80 kW/PEM
FUEL CELL MANUFACTURER
GM/Hydrogenics
RANGE – 250 mi (400 km)
MPG EQUIVALENT – n/a
MAX SPEED – 90 mph (140 km/h)

2000
Precept FCEV (concept only)

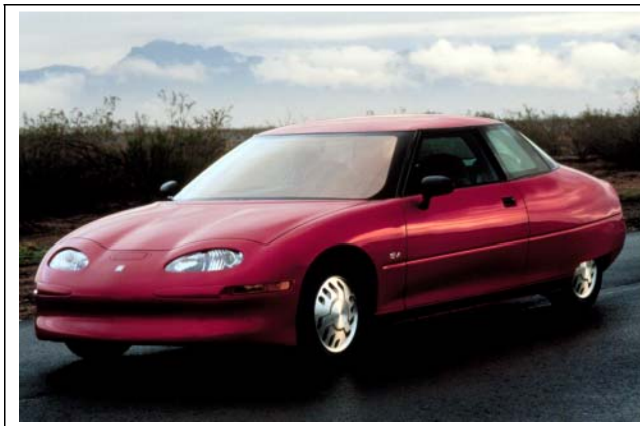
FUEL TYPE
Hydrogen (stored in metal hydride)
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
100 kW/PEM
FUEL CELL MANUFACTURER
GM/Hydrogenics
RANGE – 500 mi (800 km) est.
MPG EQUIVALENT – 108 mpg est.
MAX SPEED – 120 mph (193 km/h)

1999
Zafira (mini-van)

FUEL TYPE
Methanol
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
50 kW/PEM
FUEL CELL MANUFACTURER
Ballard
RANGE – 300 mi (483 km)
MPG EQUIVALENT – 80 mpg
MAX SPEED – 75 mph (120 km/h)

1997
Sintra (mini-van)

FUEL TYPE	
n/a	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
50 kW/PEM	
FUEL CELL MANUFACTURER	
n/a	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	



1997
EV1 FCEV

FUEL TYPE	
Methanol	
ENGINE TYPE	
Fuel cell/battery hybrid	
FUEL CELL SIZE/TYPE	
n/a	
FUEL CELL MANUFACTURER	
n/a	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

GM PATAC

Summary

Among the leaders in China is the Pan Asia Technical Automotive Center (PATAC) in Shanghai, which is a joint venture with GM and the largest Chinese auto company, Shanghai Auto Industry Corporation (SAIC). PATAC developed a functioning vehicle with modest initial support. GM is increasing its research investment in China, and SAIC has its own independent program.

Vehicles and Characteristics

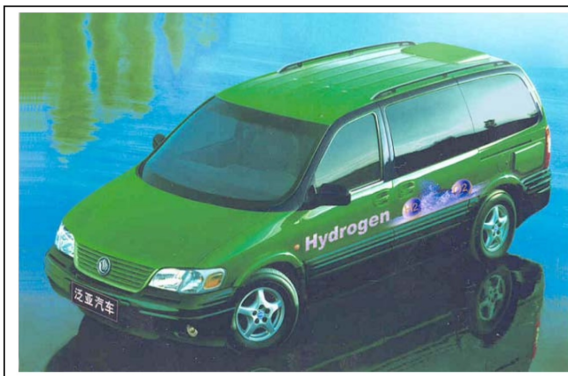
The zero-emission fuel cell wagon, called the **Phoenix**, is based on a Buick GL8 from Shanghai GM, GM's vehicle assembly joint venture in China. It was unveiled November 2002 in Shanghai. PATAC took the lead on the project, integrating the fuel cell system into the vehicle. Scientists and engineers at GM's Global Alternative Propulsion Center in the United States and Germany provided the fuel cell system, components, and technical support. A portable hydrogen refueling station designed to be compatible with hydrogen sources in China also was supplied by GM for the Phoenix.

The fully running, eight-passenger vehicle is a hybrid, powered by compressed hydrogen. "The Phoenix is serving as a test bed for further hydrogen-based research and development efforts by SAIC, GM and our technology partners," said Tim Stratford, Vice Chairman of the GM China Group. "As the global leader in fuel cell development, GM's overriding aim is to help China reduce its dependency on imported petroleum while providing a cleaner and greener environment."

Background

PATAC opened in June of 1997 in Shanghai. PATAC is a $50 million, 50/50 joint venture between GM and Shanghai Automotive Industry Corporation (SAIC).

Gallery



2001
Phoenix (mini-van)

FUEL TYPE
Compress. H_2
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
25 kW/PEM
FUEL CELL MANUFACTURER
Shanghai GM
RANGE – 125 mi (200 km)
MPG EQUIVALENT – n/a
MAX SPEED – 70 mph (113 km/h)

Honda

Summary

Honda is an acknowledged leader in fuel efficiency and emission control. Honda's fuel cell program dates to the 1980s. Honda marketed but abandoned a respectable electric vehicle in the late 1990s in favor of extremely low emission conventional engines and fuel cells. Honda is highly competitive when it comes to fuel cells, asserting a number of marketing "firsts" in friendly competition with Toyota.

Honda's fuel cell vehicles are hybrids that use ultracapacitors. Honda is under contract to buy Ballard engines through 2005. It is working hard on its own fuel cell stacks.

Honda's fuel cell vehicles are in the hands of customers in Japan and California and more are on the way, although the company has made no formal recent commercialization projections.

Honda built one methanol fuel vehicle in 1999 but quickly settled on hydrogen as its fuel of choice. Honda is investing in hydrogen fuel infrastructure innovations. It is working with Plug Power on a home refueling unit and also operates a filling station that features solar-powered electrolysis.

Vehicles and Characteristics

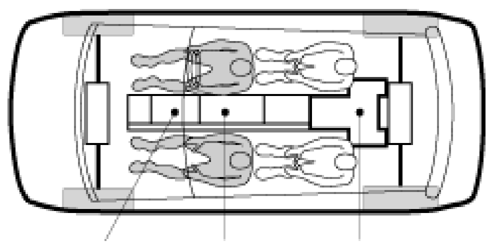
Honda claims its **FCX** is the first fuel cell car to be certified by the California Air Resources Board (CARB) and the Environmental Protection Agency (EPA) for everyday use. The FCX has been certified by CARB as a Zero Emission Vehicle (ZEV) and by EPA as a Tier-2 Bin 1, National Low Emission Vehicle (NLEV), the lowest national emission rating.

FCX acceleration is similar to that of a Civic, with a range up to 170 miles and room for four passengers. There were several versions of the FCX prior to the one delivered to California.

Honda introduced its first prototype FCV, the FCX V1, in September 1999. The two-passenger FCX V1 contained a hydrogen-powered fuel cell manufactured by Ballard Power Systems and a hydrogen-absorbing alloy to store fuel. The second version, the FCX V2, had an onboard fuel processor developed by Honda that reformed methanol into hydrogen.

The FCX V3 carried pressurized hydrogen. Honda was able to reduce the size of the fuel cell system in the FCX V3 and incorporated its ultra-capacitor with the fuel cell, creating a fuel cell hybrid.

The FCX V4 reduced the fuel cell and related components even more and moved the hydrogen tanks under the floor, creating more passenger and cargo space in the trunk. The FCX V4 has a range of 186 miles, the highest of fuel cell vehicles being demonstrated, according to Honda.



Honda showed an advanced concept vehicle called the **Kiwami** at the 2003 Tokyo Auto Show. Kiwami means "Best of the Best" or "Extreme" in Japanese. The concept vehicle has features reminiscent of the GM HyWire. The Kiwami combines a Honda stack and DC motor.

A "next-generation" hydrogen storage system, controls, and ultracapacitors are located in an H-shaped layout, creating a low center of gravity and freeing up interior space.

Background

Honda dates its history to 1946 when a research institute was founded. Honda's first product appeared in 1949 when it began manufacturing a motorized bicycle. American Honda was founded in 1959. The Honda Civic came on the market in 1972. It still regularly tops the list of fuel-efficient cars available in the United States. The Civic hit the market just in time to meet new post-oil embargo U.S. demand for fuel-efficient vehicles.

Honda began assembling Accords in the United States in 1982, and by 1989, the Accord had become the best-selling car in the United States. Honda is known as a manufacturer of efficient, durable vehicles. Less well known, but just as significant, has been Honda's positive response to motor vehicle emission control standards established by California and the U.S. government. Honda has been willing and able to meet standards other auto makers have decried as impossibilities.

Honda's product line today includes passenger cars, motorcycles, snowmobiles, marine engines, generators, power equipment, robots, and aircraft. Honda manufactured 2.9 million automobiles and 8 million motorcycles in its 2003 fiscal year, built at more than 120 manufacturing facilities in 29 countries. For 2003, Honda reported revenues of ¥7,971 billion. Honda employs nearly 127,000 workers.

Honda's new slogan for this century is "The Power of Dreams."

Honda's leadership in fuel cells has roots in its willingness to build vehicles designed to meet the spirit as well as the letter of the law on emission control. In 1975, the Honda CVCC was the first vehicle to meet U.S. federal Clean Air Act emission standards. Honda was first to market a gasoline vehicle meeting the Low Emission Vehicle (LEV) standard and the first to sell a gasoline car meeting California's Ultra Low Emission Vehicle (ULEV) standard and its Super ULEV standard. Honda also sells a natural-gas-fueled vehicle that it calls the cleanest in the world.

Honda's commitment to commercializing clean engine technology did not extend to its electric vehicles (EVs). Honda began working on an EV in 1988, beginning with a converted Honda City car. The company conducted U.S. fleet tests between 1994 and 1996 and offered the Plus EV for lease in 1997. The vehicle was well regarded, but only about 300 were put into service. Also in 1997, Honda showed a conventional ICE vehicle that it said achieved emission levels comparable to those associated with charging an electric vehicle.

Honda expressed a clear preference for hybrid vehicles and extremely low emission ICEs as bridges to the fuel cell vehicle of the future. Honda marketed its Insight hybrid in 1999 and its Civic hybrid in 2002. Honda was also the first to sell a gasoline-electric hybrid car in the United States and the first mass-market vehicle in North America with a gasoline-electric hybrid power train. Honda is using the research and knowledge from these hybrid electric vehicles to aid in the development of fuel cell technology.

Honda has been researching fuel cells since 1989, and in 1999, it introduced two FCVs: the FCX-V1 and FCX-V2. That year, Honda also became a member of the California Fuel Cell Partnership. In 2000 and 2001, Honda introduced the FCX-V3 and V4, which paved the way for the FCX limited-production vehicle — the first fuel cell vehicle in the world to receive government certification for commercial use.

Honda has a competitive attitude about fuel cell vehicles, vying with Toyota to be the first to put a vehicle in a customer's hands. Both companies released vehicles on the same day, December 2, 2002.

Honda has also made a commitment to supporting the development of a hybrid infrastructure, just as it has supported natural gas refueling. Honda has built a fueling station in California that derives hydrogen from solar power via electrolysis. It is also working on a home refueling device.

<u>Partnerships:</u>

1. Plug Power (2002), development of home hydrogen refueling system
2. Ballard Power Systems (2001), fuel cell vehicle development

Development and Commercialization

Honda has announced plans to build 300 FCVs a year for sale in the United States and Japan. Honda has a three-year supply agreement with Ballard Power Systems, which ends in 2005. In the meantime, Honda is working to improve the performance of its fuel cell stack in cold and freezing conditions. The latest generation works up to -20°C (-4°F) and performs well under higher temperatures. This new stack is lighter, smaller, and 10% percent more fuel efficient than the previous version.

The city of Los Angeles, California, has leased five Honda fuel cell FCXs for $500 per month per vehicle for two years. The first was delivered on December 2, 2002. On that same day, Honda delivered an FCX to Japan's Cabinet Office for $6,500 (¥800,000) per month under a 12-month lease. In the same month, Honda signed a supply agreement with Ballard Power Systems for up to 32 Mark 902 fuel cell modules through 2005 and support services for Honda's fuel cell vehicle customer deliveries in the United States and Japan.

Honda asserts it was the first to lease a fuel cell car to a private company, the Iwatani International Corporation at the Ariake Hydrogen Station in Koto-ku, Tokyo.

Honda plans to lease about 30 fuel cell cars to California and Japan over the next few years. Honda recently announced that it would supply San Francisco with 2 FCXs.

Gallery

FUEL TYPE
Compress. H_2 @ 5,000 psi
ENGINE TYPE
Fuel cell/Honda ultra-capacitors
FUEL CELL SIZE/TYPE
85 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 900 Series
RANGE – 220 mi (355 km)
MPG EQUIVALENT – ~50 mpg
MAX SPEED – 93 mph (150 km/h)

2002
FCX

FUEL TYPE
Compress. H_2 @ 5,000 psi
ENGINE TYPE
Fuel cell/ Honda ultra-capacitors
FUEL CELL SIZE/TYPE
85 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 900 Series
RANGE –185 mi (300 km)
MPG EQUIVALENT – ~50 mpg
MAX SPEED – 84 mph (140 km/h)

2001
FCX-V4

FUEL TYPE
Compress. H_2 @ 3,600 psi
ENGINE TYPE
Fuel cell/Honda ultra-capacitors
FUEL CELL SIZE/TYPE
62 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 700 Series
RANGE – 108 mi (173 km)
MPG EQUIVALENT – n/a
MAX SPEED – 78 mph (130 km/h)

2000
FCX-V3

1999
FCX-V2

FUEL TYPE	
Methanol	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
60 kW/PEM	
FUEL CELL MANUFACTURER	
Honda	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – 78 mph (130 km/h)	

1999
FCX-V1

FUEL TYPE	
Hydrogen (stored in metal hydride)	
ENGINE TYPE	
Fuel cell/battery hybrid	
FUEL CELL SIZE/TYPE	
60 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard Mark 700 Series	
RANGE – 110 mi (177 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 78 mph (130 km/h)	

Hyundai

Summary

Hyundai is a latecomer to fuel cells, but it has extensive experience in electric and hybrid vehicle technology and appears to have caught up with the fuel cell competition, in partnership with United Technologies. Hyundai plans to begin leasing a few fuel cell hybrid versions of its Santa Fe SUV in 2004. While these vehicles use gaseous hydrogen, Hyundai has expressed continued interest in methanol fuel and onboard reforming.

Vehicles and Characteristics

Hyundai relied heavily on its EV background to produce a working fuel cell SUV in 2000. The vehicle was well received, and the 2002 version, a hybrid, is a better performer.

The **Santa Fe FCEV** is a hydrogen-powered, non-hybrid fuel cell vehicle. The fuel cell system was manufactured by UTC Fuel Cells, the drive train by Enova Systems, and the hydrogen storage system by Quantum Technologies. It has a range of 100 miles and can reach speeds of 77 mph. Hyundai asserts its Santa Fe FCEV is the world's first drivable vehicle with a fuel system that stores hydrogen compressed up to 5,000 psi.

The **Santa Fe FCHEV** is the fuel cell-battery hybrid version of the Santa Fe SUV, with a 250 mile range.

Background

Hyundai was formed in 1946 as auto service center. It built its first cars in 1967 under license from Ford, but it produced its own product, the Pony, in 1974, with support from Mitsubishi. Hyundai entered the U.S. market in 1995. Hyundai bought Kia Motors in 1998. DaimlerChrysler owns about nine percent of Hyundai.

Hyundai produced about 1.7 million cars in 2002 and reported revenue of $22 billion. Employment is about 60,000. Its corporate motto is "Pursuing Happiness Through Cars."

Hyundai has significant experience with hybrid electric drive, unveiling the first of four hybrid electrics in 1995. It produced all-electric versions of a small car, a sedan and an SUV between 1997 and 2000. Its fuel cell research effort was launched in 2000 with announcement of collaboration with United Technologies (then International Fuel Cells). Six months later, it rolled out a fuel cell version of its Santa Fe SUV.

Partnerships:

1. United Technologies Corporation (2000), fuel cell engines and vehicles
2. Quantum, hydrogen storage
3. Enova Systems (2002), electronics

Development and Commercialization

Hyundai is working closely with the Korean government on the development of fuel cell systems for public transportation. Korean interest in hydrogen has increased recently. The company's FCVs carry compressed hydrogen, but the company asserts it believes the path to commercialization lies with liquid fuel and is working on a methanol reformer. Hyundai also is working on its own fuel cell engine technology.

Hyundai appears to be treading a careful line in its fuel cell development. Its relationship with UTC clearly has borne fruit; the companies reaffirmed their working relationship in 2003. Hyundai hopes to lease some vehicles in 2004.

Said Dong Jin Kim, president and CEO, "By 2004, Hyundai will be testing and evaluating the performance of fuel cell vehicles in fleet applications, allowing us to further refine the application of fuel cells for every-day transportation."

Hyundai believes its FCVs will be able to outperform its conventional vehicles.

Hyundai has announced a plan with Kia Motors Corporation to test 32 hydrogen FCVs in the United States beginning in 2004. The company suggests it may sell 10,000 fuel cell vehicles in Korea by the end of the decade, with commercial production by 2020.

Gallery

2002
Santa Fe FCHEV

FUEL TYPE
Compressed H_2
ENGINE TYPE
Ambient-pressure fuel cell hybrid
FUEL CELL SIZE/TYPE
75 kW/PEM
FUEL CELL MANUFACTURER
UTC Fuel Cells
RANGE – 250mi (402 km)
MPG EQUIVALENT – n/a
MAX SPEED n/a

2000
Santa Fe FCEV

FUEL TYPE	
Hydrogen	
ENGINE TYPE	
Fuel cell (hybrid in 2002)	
FUEL CELL SIZE/TYPE	
75 kW/PEM	
FUEL CELL MANUFACTURER	
United Technologies	
RANGE – 100 mi (160 km)	
MPG EQUIVALENT – 50–60 mpg	
MAX SPEED – 77 mph	

2003
Mr. Wagon (concept car)

FUEL TYPE	
Hydrogen	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
n/a	
FUEL CELL MANUFACTURER	
General Motors	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

2001
Covie (concept car)

FUEL TYPE	
Hydrogen	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
n/a	
FUEL CELL MANUFACTURER	
General Motors	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

Mazda

Summary

Mazda Motor Corporation produces passenger cars and commercial vehicles and is the only automaker that uses three types of engines. Mazda and its equity partner, Ford, are actively exploring FCVs and hydrogen internal combustion engines. (See Ford section for additional discussion.)

Vehicles and Characteristics

In 1997, Mazda produced the **Demio**, a compact electric FCV that stored hydrogen in metal hydrides.

Mazda's current fuel cell vehicle is the **Premacy**, released in 2001. The Premacy uses methanol as fuel. It was awarded road permits in 2001 and is currently undergoing public road testing in Japan.

Background

Mazda dates its corporate history to 1920. It began producing vehicles in 1931 with a three-wheel truck. Its first passenger cars were produced in 1960. Mazda has pursued engine innovations for several decades. Its work on rotary engines began in 1961 when it began working with a German company, NSU/Wankel. Its first commercial rotary engine vehicle reached the market in 1967. Its partnership with Ford began in 1969; 10 years later, Ford acquired a 25% stake.

.

Mazda produces about one million vehicles per year. Mazda exports to 146 countries, with U.S. exports dating to 1970. In 2002, Mazda reported income of $19.7 billion. It employs about 36,000 workers.

Mazda has been studying hydrogen as a fuel source since 1990. In 1997, Mazda tested its first fuel-cell-powered car, the HR-X, a fuel cell version of Mazda's Demio compact. It featured a fuel cell stack developed in-house. Mazda joined the Ford, DaimlerChrysler, and Ballard collaboration in 1998. Two Premacy fuel cell models (one a hybrid) released in 2001 show the impact of the collaboration with Ford and feature Ballard fuel cell engines.

<u>Partnerships:</u>

1. Ballard (1998), fuel cell research and development
2. Ford (1998), fuel cell research and development
3. DaimlerChrysler-Benz (1998), fuel cell research and development
4. DaimlerChrysler (1999), fuel cell car promotion in Japan
5. Nippon Mitsubishi Oil (1999), fuel cell car promotion in Japan
6. Volvo

Development and Commercialization

Mazda says it wants to be the world’s leader in commercially produced fuel-cell-powered components for vehicles.

Mazda joined DaimlerChrysler, Japan Holding Ltd., and Nippon Mitsubishi Oil Co., Ltd., in a government-supported project to demonstrate methanol FCVs. DaimlerChrysler and Mazda will provide one car each for test runs, and Nippon Mitsubishi will provide the fuel needed for the tests. The project will cost more than ¥1 billion and will be supported by up to ¥300 million from Japan’s Ministry of International Trade and Industry.

Hydrogen Combustion

Mazda is considered a leader in hydrogen combustion technology. Between 1991 and 1995, it showed four vehicles, including a station wagon, operating on hydrogen rotary engines. In 2003, Mazda unveiled a new generation of hydrogen combustion vehicle, utilizing a direct-injection rotary engine (called the RENESIS) and an RX-8 body. The vehicle can operate on hydrogen (stored in a pressurized tank) or on gasoline.

Mazda has announced ambitious plans to commercialize its hydrogen vehicle, with a target date of 2007 for production. A test of a customer-ready vehicle is still at least a year off, however, because of the limited range with the single tank of compressed hydrogen carried on the demonstration vehicle.

Gallery

2003
RX-8 Hydrogen RE

FUEL TYPE	Hydrogen-gasoline hybrid
ENGINE TYPE	Rotary Internal Combustion
FUEL CELL SIZE/TYPE	n/a
FUEL CELL MANUFACTURER	Mazda
RANGE – variable	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

2001
Premacy FC- EV

FUEL TYPE
Methanol
ENGINE TYPE
Fuel cell
FUEL CELL SIZE/TYPE
85 kW/PEM
FUEL CELL MANUFACTURER
Ballard Mark 900 Series
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – 77 mph (124 km/h)

1997
Demio

FUEL TYPE
Hydrogen (Stored in a metal hydride)
ENGINE TYPE
Fuel cell/ultra capacitor hybrid
FUEL CELL SIZE/TYPE
20 kW/PEM
FUEL CELL MANUFACTURER
Mazda
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – 60 mph (90 km/h)

Mitsubishi

Summary

Mitsubishi, Japan's oldest automaker, has extensive experience with electric and hybrid vehicles and has been working on fuel cell vehicles since the 1990s. Mitsubishi has announced plans to have a commercial FCV by 2005, but DaimlerChrysler's increasing stake and influence mean commercialization decisions will be tied to those of DCX. Mitsubishi released an attractive new minivan in 2003 featuring a Daimler-Ballard fuel cell under the body of a new Mitsubishi model called the Grandis. It is undergoing road tests in Japan.

Vehicles and Characteristics

In 2001, Mitsubishi released the **SpaceLiner,** a concept fuel cell vehicle that runs on methanol.

Its latest fuel cell vehicle, the **Grandis**, debuted in 2003 and shows Daimler's influence. The minivan is powered by DaimlerChrysler's compressed hydrogen fuel cell system and can reach speeds up to 87 mph.

Background

The first Mitsubishi company was a shipping firm established in 1870. It produced its first cars in 1917 and by 1925 had formed a business link with Chrysler. The partnership did not survive the war. Because of fuel shortages, Mitsubishi built an electric bus in 1946. It restarted its auto production in 1950, concentrating on small cars. Mitsubishi Motors Corp. was established as a separate company in 1970; Chrysler was a 15% owner. Chrysler began selling Mitsubishi vehicles under the Dodge and Plymouth badges beginning in1978.

Mitsubishi's four-wheel-drive technology dates to 1933, and the company returned to the technology beginning in 1982. In 1996, Mitsubishi introduced direct injection technology, which is gaining momentum as a diesel engine engineering option.

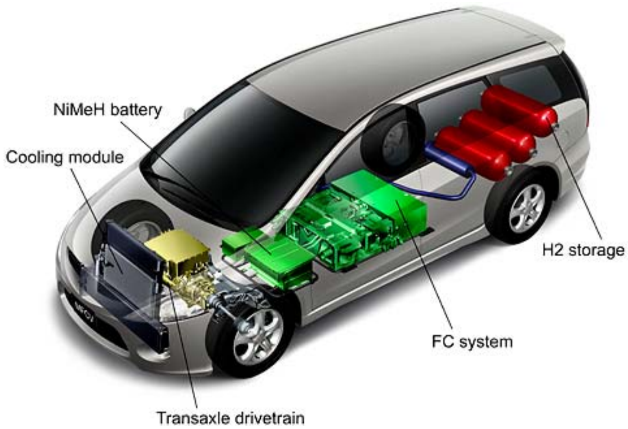
The company in recent years produced a full line of vehicles, from minicars to passenger autos, trucks, and buses. In 2002, Mitsubishi Motors sold 1.6 million passenger cars and had net sales of ¥3,885 billion. Mitsubishi employs more than 45,000 people.

DaimlerChrysler, Chrysler's successor, owns about 37.5% of Mitsubishi, and their relationship is expanding.

Mitsubishi's interest in electric drive technologies dates to World War II. The company began limited production of an electric van in 1971, making it one of the newly independent motor company's first products. Development of an electric drive Lancer began in 1991, and a Mitsubishi EV went on commercial sale in Japan in 1994. Mitsubishi has also worked since the 1990s on hybrid vehicle configurations. A Mitsubishi FTO-EV set a distance record of nearly

1,000 miles in 1999, and in 2001, an Eclipse EV traveled 400 km on a single charge on public roads.

Mitsubishi exhibited a methanol-powered fuel cell concept vehicle at the Tokyo Motor Show in 1999 in conjunction with Mitsubishi Heavy Industries.



Its Grandis fuel cell vehicle minivan was released in 2003 and certified for operation on public roads. The selection of the Grandis platform is considered significant since the minivan is a new model for 2004. The minivan is being tested as part of the Japan Hydrogen and Fuel Cell Vehicle demonstration.

Partnerships:

1. Chrysler, (1998) fuel cell power system

Development and Commercialization

The Grandis was approved for public roads in Japan in November of 2003.

Mitsubishi says it chose the minivan because the global minivan market is growing quickly and "because it is more environmentally friendly to carry multiple people in a single vehicle – something that is aligned with the interests of those researching and purchasing alternative fuel vehicles."

Gallery

2003
Grandis FCV

FUEL TYPE
Compress. H_2
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
68 kW/PEM
FUEL CELL MANUFACTURER
DaimlerChrysler/Ballard
RANGE – 92 mi (150 km)
MPG EQUIVALENT – n/a
MAX SPEED – 87 mph (140 km/h)

2001
SpaceLiner (concept only)

FUEL TYPE	
Methanol	
ENGINE TYPE	
Fuel cell/battery hybrid	
FUEL CELL SIZE/TYPE	
40 kW/ PEM	
FUEL CELL MANUFACTURER	
n/a	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

1999
MFCV (concept only)

FUEL TYPE	
Methanol	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
n/a	
FUEL CELL MANUFACTURER	
Mitsubishi	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

Nissan

Summary

Nissan has proceeded with less fanfare than its Japanese competitors but appears to be determined to keep pace in fuel cell vehicle development. Several Nissan vehicles have been released since 1999. Late in 2003, Nissan announced plans to begin leasing an X-Trail FCV, a fuel cell hybrid SUV, early in 2004. Nissan worked with Ballard stacks in the early years, but its customer-ready vehicles apparently will utilize United Technologies Corporation fuel cells.

Vehicles and Characteristics

The first fuel cell powered Nissan was the **R'Nessa**, released in 1999. It used methanol fuel. The Nissan **Xterra**, unveiled in 2000, is a fuel cell/battery hybrid prototype SUV.

The third-generation **X-Trail** was approved by the Japanese Minister of Land, Infrastructure and Transport for operation in Japan in 2002. It is being leased on a limited basis, two years ahead of schedule. There are two custom designed versions of the X-Trail: the Rider and the Axis.

At the 2003 Tokyo Motor Show, Nissan unveiled the **Effis**, a commuter concept car.

Background

Nissan's corporate history dates to 1911 when a predecessor manufacturing company was established in Tokyo. That company took over Datsun in 1933 and in 1934 adopted the Nissan name. Renault purchased 36% of Nissan in 1999. Nissan sold 2.7 million units in 2002, with revenue of ¥6,828 billion (consolidated basis). The company employs 31,128 workers directly (127,625 including subsidiaries).

Nissan has a long history in electric drive vehicles. In 1992, Nissan became the first Japanese automaker to mass produce an EV for sale. It released its Altra EV station wagon in California and Europe in 1998. Nissan has two electric cars, the Altra EU and the Hypermini, as well as a hybrid Tino. Nissan's strategy for EVs tends to focus on sport utility vehicles, an approach it has carried over to its fuel cell development. Nissan believes its expertise in electric drive vehicles is of direct benefit to its fuel cell program.

Nissan has released an FCV every year since 1999, beginning with the R'nessa. Xterra SUVs were released in 2000 and 2001, and X-Trails in 2002 and 2003.

<u>Partnerships</u>:

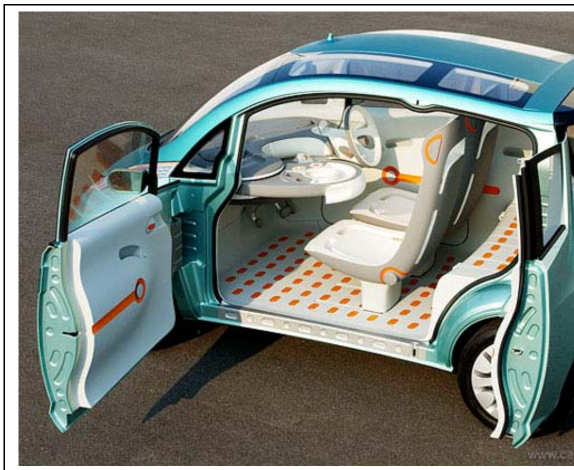
1. Renault (1999), creating a powerful bi-national alliance
2. PSA Peugeot (2003), hydrogen storage
3. Suzuki (1999), to develop DMFCs for vehicles
4. Japanese Government, to develop DMFCs for vehicles

Development and Commercialization

Nissan is part of the California Fuel Cell Partnership and is participating in the Japanese Government's fuel cell demonstration program. Nissan is also working with Renault on fuel cell cars that run on gasoline.

Nissan's long-range fuel cell production strategy is not public, but Japanese automakers are being encouraged to develop fuel cell vehicles by the Japanese government. Nissan's main thrust has been to develop extremely low emission gasoline-powered vehicles, which it has characterized as providing benefits equivalent to those from fuel cell vehicles. Nissan says it "expects to have the technology for FCV production by 2005."

Gallery



2003
Effis (commuter concept vehicle)

FUEL TYPE
n/a
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
n/a
FUEL CELL MANUFACTURER
n/a
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – n/a

2002
X-Trail

FUEL TYPE
Compress. H_2 @ 5,000 psi
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
75 kW/PEM
FUEL CELL MANUFACTURER
UTC Fuel Cells (Ambient-pressure)
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – 78 mph (125 km/h)

2001/2000
Xterra

FUEL TYPE	
Compress. H_2	
ENGINE TYPE	
Fuel cell/battery hybrid	
FUEL CELL SIZE/TYPE	
85 kW/ PEM	
FUEL CELL MANUFACTURER	
Ballard Mark 900 Series and UTC Fuel Cells (two prototypes)	
RANGE – 100 mi (161 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 75 mph (120 km/h)	

1999
R'nessa

FUEL TYPE	
Methanol	
ENGINE TYPE	
Fuel cell/battery hybrid	
FUEL CELL SIZE/TYPE	
10 kW/ PEM	
FUEL CELL MANUFACTURER	
Ballard Mark 700 Series	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – 44 mph (70 km/h)	

PSA/Peugeot Citroën

Summary

Peugeot is a leading maker of electric vehicles and is publicly committed to fuel cells in the next decade. PSA officials expect FCVs to be mass marketed by 2015 and to be cost- competitive with conventional systems by that time. Alain Bugat, general manager for the CEA (The French Atomic Energy Commission, PSAs partner), said in mid-2003: "On hydrogen power, we've reached the point of no return. It will happen."

Vehicles and Characteristics

Peugeot has developed two hydrogen-powered cars.

The **HydroGen**, a five-seater passenger car, was released in 2001. The hydrogen is stored in five tanks installed beneath the front and rear seats.

Also in 2001, Peugeot unveiled the **Taxi PAC**.

In 2002, Peugeot introduced the **H2O** firefighting concept vehicle. The two-seater H2O is an electric vehicle with batteries, fitted with a fuel cell auxiliary power unit (APU) that supplies power to various firefighting equipment, such as pumps, smoke extractors, and emergency communication systems. The vehicle creates hydrogen onboard, via a solution of sodium borohydride and a catalyst.

Background

PSA Peugeot Citroën is the second largest carmaker in Europe, serving 15% of the market. It ranks sixth worldwide. Other group members include Faurecia, an automotive equipment manufacturer; Gefco, a transportation and logistics company; and the Banque PSA Finance, a group of automotive finance companies. Peugeot was founded in 1896 by Armand Peugeot; Citroën started production in 1919. In 1934, Citroën was bought by Michelin, which sold it to Peugeot in two phases between 1974 and 1976.

PSA Peugeot Citroën sold 3.3 million vehicles in 2002, including 2.6 million in Western Europe. It has facilities in six countries and significant joint venture operations with Renault and Fiat. PSA employs more than 17,000 people worldwide. Peugeot companies reported revenue of €53 billion in 2002.

Peugeot markets a variety of products utilizing alternative fuels, including electric vehicles and vehicles operating on natural gas and liquid petroleum gas (LPG).

Peugeot has been working on electric vehicle technology since 1989 and began to supply electric vehicles to corporate and municipal fleets in 1995. It has several EVs in production, such as the

Peugeot 106 Electric, the Citroën Saxo Electric, the Electric Peugeot Partner, and the Citroën Berlingo.

Peugeot also markets an electric scooter Scoot'elec (Le Scooter Electrique), which went on sale in 1996. Peugeot's hybrid vehicle, the Citroën Xsara Dynalto, is expected shortly.

Peugeot's fuel cell program is based in part on its experience with battery EVs. Peugeot is supported by the French government, which has been financing fuel cell research since the 1990s. Peugeot claims it has been working on fuel cells for 30 years. Its recent activity dates to its work with other European automotive companies on designing fuel cell cars within the EU's Hydro-Gen and FEVER programs from 1994 to 1998.

Peugeot unveiled two fuel cell-battery hybrids in 2001, including a taxi. In 2002, Peugeot created a stir at the Paris Auto Show with the H20, a concept electric drive "fire engine" that features a small fuel cell "range extender" that runs on sodium borohydride fuel — this vehicle is suitable for use in an oxygen-starved environment, such as a major fire. Peugeot apparently has not settled on a fuel cell engine supplier.

Partnerships:

1. Delphi (1999), fuel cell research
2. Renault, (2001), fuel cell research
3. Nissan (2003), hydrogen storage
4. Millennium Power
5. Hy Power

Development and Commercialization

The French Ministry began a project with Peugeot, Renault, Air Liquide, De Nora, and Delphi in 2001 to further fuel cell technology research. The work will mostly take place at a new national fuel cell center funded primarily by the Ministry. Peugeot and Renault will work together to create fuel cell vehicle prototypes.

Peugeot is researching electric power and biofuels. In February 2003, Peugeot chief executive Jean-Martin Folz stated that the technical barriers to fuel cell cars would prevent them from being ready for public consumption before 2015. He said that Peugeot would be concentrating on hybrid electric cars instead.

Peugeot believes the first commercial fuel cell vehicles will be electric hybrids with small fuel cells used as range extenders. Commercialization could take place between 2005 and 2010. In the meantime, Peugeot participates in many European research programs (such as Hydro-Gen, Nemecel, and Bio H2) and French programs (such as Predit), as well as in projects backed by the French Ministry for National Education, Research and Technology.

After 2010, Peugeot expects that "fuel cells will be the main source of energy for vehicles" configured using onboard reformers and syngas or ethanol.

After 2020, Peugeot sees hydrogen fuel-battery hybrids with long-range capability. PSA says it has about 100 employees working on fuel cells.

Gallery

2002
H2O Firefighting Concept

FUEL TYPE	Catalyzed chemical hydride-sodium borohydride
ENGINE TYPE	Battery/fuel cell APU
FUEL CELL SIZE/TYPE	n/a
FUEL CELL MANUFACTURER	n/a
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – 77 mph (124 km/h)	

2001
Taxi PAC

FUEL TYPE	Compressed H_2 @4,300 psi
ENGINE TYPE	Fuel cell/ battery hybrid
FUEL CELL SIZE/TYPE	55 kW/PEM
FUEL CELL MANUFACTURER	H Power
RANGE – 188 mi (300 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 60 mph (95 km/h)	

2001
Hydro-Gen

FUEL TYPE	Compressed H_2
ENGINE TYPE	Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE	30 kW/PEM
FUEL CELL MANUFACTURER	Nuvera Fuel Cells
RANGE – 186 mi (300 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 60 mph (95 km/h)	

Renault

Summary

Renault's fuel cell activities are proceeding in the shadows cast by larger competitors. Renault's only publicly released fuel cell vehicle prototype was the FEVER in 1997. Since then, Renault has finalized a research partnership with BMW and Delphi on APUs for diesel trucks and launched a gasoline reformer program jointly with its partner, Nissan.

Vehicles and Characteristics

In 1997 Renault, along with PSA Peugeot, developed the **Laguna Estate**. It is a concept car that runs on liquid hydrogen, based on the Renault Laguna Nevada station wagon.

Background

Renault was founded in 1898 by Louis Renault with release of a prototype that went into production the following year. The Renault group today has over 350 industrial and commercial sites in 36 countries, and employs 132,500 people worldwide. In 2002, the group generated revenues of €36.3 billion.

Renault purchased 36 percent of Nissan in 1999, declaring that a full merger was "not desirable." The relationship brought needed capital to Nissan and has resulted in 2002 in combined sales of 5.2 million vehicles, making the collaboration one of the world's top five automobile manufacturers.

Renault unveiled its first, and to date only, functional FCV in 1997. Called the FEVER (Fuel Cell Electric Vehicle for Efficiency and Range), it was a Laguna station wagon fitted with a 30-kW hybrid PEM-battery system developed by Italy's De Nora Company (Nuvera). FEVER was the product of a joint French-Italian-Swedish collaboration launched in 1994 and partially funded by the European Commission. FEVER operated on liquid hydrogen.

Renault has had a relationship with Delphi and BMW since 2000. Delphi intends to supply solid oxide fuel cell APUs. BMW intends to use the units in its passenger cars. Renault plans to use them in diesel hybrid trucks. Plans call for prototypes by 2008 and commercial products by 2015.

In 2001, Renault and Nissan said they intended to develop gasoline powered FCVs, with a market date as early as 2005. (The announcement came on the heels of a similar commitment by Toyota, GM, and ExxonMobil, which has since moved to the back burner.)

Renault developed a relationship with Nuvera, which is developing multi-fuel reformers, and approached TotalFinaElf, Europe's number-one fuel supplier, for work on fuel quality. The goal of the collaboration was a customer-ready reformer by 2004 leading to possible commercialization by 2010, according to Nuvera.

Partnerships:

1. Nissan (1999), creating a powerful bi-national alliance
2. BMW (2000), fuel cell auxiliary unit
3. Delphi (2000), fuel cell auxiliary unit
4. PSA Peugeot (2001), fuel cell research
5. Nuvera Fuel Cells (2002), fuel cell processor
6. UTC Fuel Cells (2002), engines for fuel cell vehicles
7. TotalFinaElf (2002), fuel for fuel cell vehicles

Development Commercialization

Like many other major automotive companies, Renault plans to have a fuel cell vehicle in production by 2010. It is currently working with Nissan in creating a fuel cell car that runs on gasoline and hopes to have the vehicle ready for production by 2005.

The French Ministry began a project in 2001 with Renault, Peugeot, Delphi, De Nora, Air Liquide, and other companies to further fuel cell technology. Renault will work with Peugeot to develop a prototype vehicle.

Gallery

1997
Laguna Wagon (FEVER Project)

FUEL TYPE	Liquid hydrogen
ENGINE TYPE	Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE	30 kW/PEM
FUEL CELL MANUFACTURER	Nuvera Fuel Cells
RANGE –	250 mi (400 km)
MPG EQUIVALENT –	n/a
MAX SPEED –	75 mph (120 km/h)

Suzuki

Summary

Suzuki, the world's largest motorcycle manufacturer, has been a partner with GM for many years and is part of GM's FCV effort, focusing on engineering areas related to small vehicle production, such as miniaturization and weight reduction. Suzuki is participating in the government-supported Japanese FCV demonstration and unveiled two concept cars in 2003.

Vehicles and Characteristics

Suzuki recently unveiled the **Mobile Terrace**, a six-passenger concept that uses drive-by-wire technology, based on GM's Hy-Wire platform. The fuel cell and motor are placed under the floor. The Mobile Terrace has three rows of seats and room for six passengers. The doors and roof slide open. GM and Suzuki jointly designed **Mr. Wagon**, a mini fuel cell car that seats four adults. Both vehicles were rolled out in 2003.

The 2001 concept fuel cell electric hybrid from Suzuki is the **COVIE.** It is a compact two-seater designed for short-range urban use. It was voted Best Environmental Concept Car by Automotive News in 2001.

Background

In 1909, Michio Suzuki founded the Suzuki Loom Company in the village of Hamamatsu, Japan. In 1952, Suzuki brought a motorized bicycle to market, and by 1954, Suzuki had added Motor Co. to its name and was producing 6,000 two-wheelers per month. The following year, Suzuki developed its first car.

In 1991, it began producing cars in Korea in partnership with Daewoo. Suzuki has a relationship with GM that dates back to 1981. In 2000, it became an Original Equipment supplier to GM. A year later, the companies formally agreed to collaborate on fuel cells. GM owns about 20% of Suzuki.

Suzuki sells about 1.7 million automobiles a year, about half of them in Japan. It sells a similar number of motorcycles. Sales in 2002 totaled $12.7 billion. Employment in Japan was about 13,000. Suzuki produces small engines for a variety of specialty vehicles, from lawn mowers to snowmobiles to wheelchairs.

Suzuki has worked for years on electric drive vehicles and, in 2002, showed a single-seat gasoline-electric hybrid called the Twin. It also supplies GM with parts for its Triax vehicle, which has both a hybrid electric and conventional configuration.

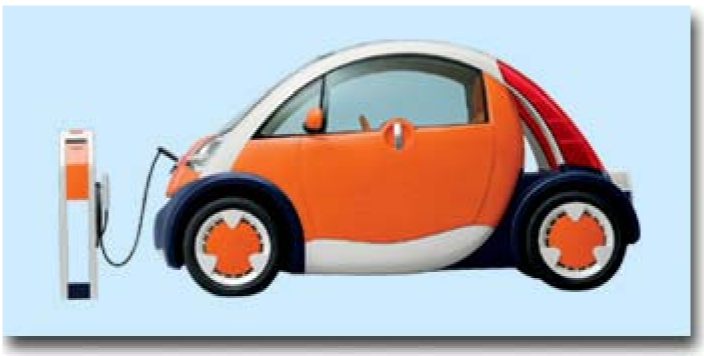
Suzuki is now part of the GM development team. Suzuki expects to concentrate on those development areas it knows best, such as miniaturization.

Partnerships:

1. Nissan (1999), DMFC development
2. GM (2001), small car fuel cell technology

Development and Commercialization

Suzuki is a member of the Japan hydrogen and fuel cell demonstration project (JHFC), a Tokyo area demonstration involving vehicles from eight companies and nine hydrogen stations in Tokyo and Yokohama. Suzuki has worked with Nissan and the Japanese government on direct methanol fuel cells for vehicles.



Under an agreement signed in 2001, Suzuki is collaborating with GM on fuel cell technology. Suzuki has access to GM's advanced fuel cell technology, and its engineers are working at GM's Global Alternative Propulsion Center (GAPC) in Europe.

Gallery

2003
Mobile Terrace (concept car)

FUEL TYPE	Hydrogen
ENGINE TYPE	Fuel cell
FUEL CELL SIZE/TYPE	n/a
FUEL CELL MANUFACTURER	GM
RANGE –	n/a
MPG EQUIVALENT –	n/a
MAX SPEED –	n/a

2003
Mr. Wagon (concept car)

FUEL TYPE	
Hydrogen	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
n/a	
FUEL CELL MANUFACTURER	
GM	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

2001
Covie (concept car)

FUEL TYPE	
Hydrogen	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
n/a	
FUEL CELL MANUFACTURER	
GM	
RANGE – n/a	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

Toyota

Summary

Toyota has aggressively pursued hybrid electric drive systems. Its hybrid Prius has sold more than 100,000 units and was updated for 2004. The company hopes to sell 300,000 hybrids a year by 2005. Toyota has settled on its Highlander SUV body for its initial fuel cell products. Limited leasing is under way. Toyota enjoys a friendly rivalry with Honda over which could claim to be "first" to achieve various development and commercialization benchmarks.

Toyota's long-term view is that fuel cells alone are not a panacea, but they will enable engineering innovations and weight reduction that may finally remove the motor vehicle from the pollution equation.

Toyota is concerned about infrastructure and willing to invest in initial hydrogen fueling stations. Toyota also retains the hope that a clean gasoline and advances in reformer technology will yield a liquid fuel market entry strategy. Toyota plans to establish California fuel cell "community" partnerships of government, business, and higher education to tackle product, infrastructure, and consumer-acceptance challenges.

Vehicles and Characteristics

Toyota has introduced a line of hybrid fuel cell vehicles based on the Highlander called the **FCHV** (Fuel Cell Hybrid Vehicle). The **FCHV-3, FCVH-4,** and **FCHV-5** were introduced in 2001, with an update in 2002. The **FCHV-5** features a "clean hydrocarbon fuel" option. The FCHV seats five, attains speeds up to 95 mph, has a range of more than 180 miles, and contains engine space for gasoline so the car can be used when there is no hydrogen available. It has improved on the reliability, cruising distance, functionality, cost, and cold weather performance of previous versions.

The FCHV-5 has four 5,000-psi hydrogen fuel tanks, generating a peak of 90 kW of electricity. The Toyota FCHV has been certified by CARB as a zero-emissions vehicle.

Toyota has two fuel cell versions of its RAV4 SUV, the RAV4 FCEV, with one running on methanol and the other running on hydrogen stored in a metal hydride. The hydrogen- powered FCEV receives extra power from batteries, which supplement the fuel cell during acceleration.

The **Fuel Cell Innovative Emotion-Sport (FINE S)** concept car debuted at the North American International Auto Show in January 2003. The FINE-S is similar in concept to the G Hy-Wire: the fuel cell system is located the floor, and there are four independent wheel motors.

Background

Toyota Motor Corporation was spun off from Toyoda Automatic Loom Works in 1937. Toyoda had entered the vehicle business a few years earlier. Toyota entered the industrial vehicle market in 1956. It merged with Hino Motors, maker of trucks and buses, in 1966. Manufacturing in the United States began in 1988; Toyota has built 10 million cars in North America.

Toyota took over Daihatsu in 1998. Toyota has sales and/or manufacturing relationships with Volkswagen Audi, PSA Peugeot Citroen, Isuzu, and others.

Toyota is the third largest automaker in the world, with global auto and bus sales in 2002 totaling 5.5 millions units. Revenue was ¥14,318 billion. Toyota owns 12 plants and 11 manufacturing subsidiaries in Japan and an additional 45 manufacturing companies in 26 countries throughout the world. Toyota and Lexus employ 264,096 people worldwide, and they market their vehicles, which range from minivans to trucks, in more than 140 countries and regions. Toyota is also starting to enter the telecommunications, prefabricated housing, and leisure boat markets.

Toyota's interest in electric vehicles dates to the 1970s. Several vehicles were developed with respectable performance. Toyota responded to the California Air Resources Board's ZEV mandate in 1996 with a battery powered RAV-4. Toyota stuck with the product until 2003, finally ceasing production as a result of poor sales. In 1997, Toyota introduced the hybrid electric Prius, which has sold well (>100,000 units worldwide) and represents Toyota's view of the future of electric vehicles. Toyota credits the RAV-4 EV for contributing the drive system to the Prius.

Toyota began working on fuel cells in 1992 and introduced its first hydrogen fueled vehicle in1996, proudly claiming it as a home-grown vehicle that would generate 100 patents. Several other vehicles have followed.

Toyota began road tests in 1999 and has logged more than 80,000 miles on test tracks and public roads.

<u>Partnerships:</u>

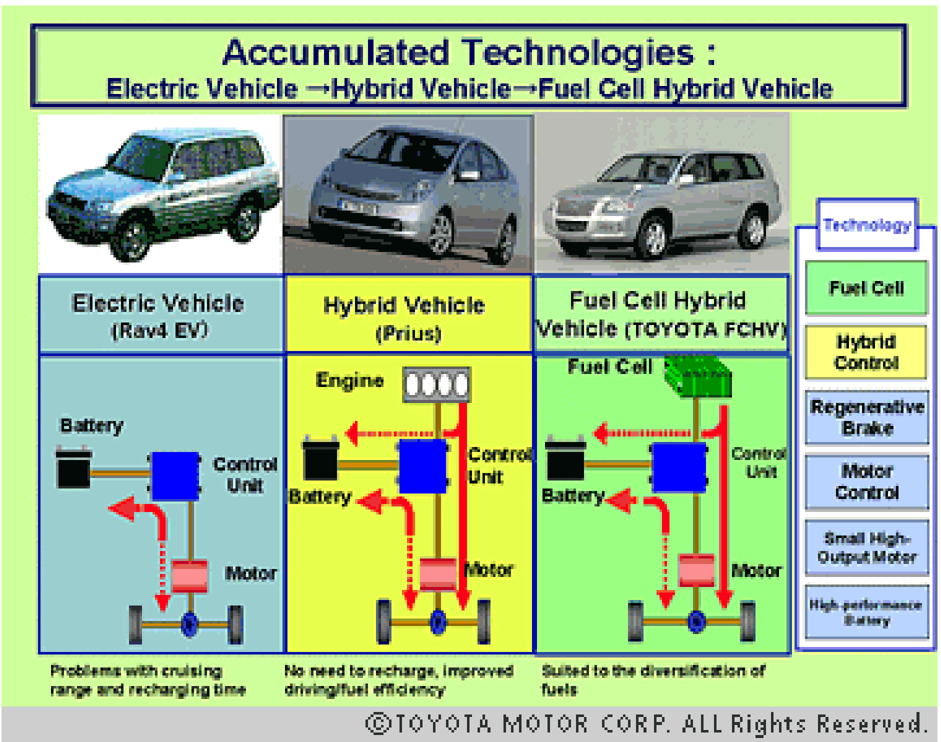
1. GM (1999), fuel cell technology
2. Daihatsu (1999), fuel cell research and development
3. ExxonMobil (2001), fuel cell research
4. Hino Motors (2002), fuel cell bus
5. Giner Inc.

Development and Commercialization

In December 2002, Toyota leased a FCHV to each of the four central Japanese government agencies for 30 months at ¥1.2 million (about $9,800 at the time the leases were signed). Toyota has also leased another six FCVs to various corporations and government branches in Japan.

In addition, Toyota delivered one FCHV each to the University of California-Irvine and University of California-Davis, with plans to provide four more vehicles for 30-month evaluation periods for $10,000 per month.

Toyota has not announced firm plans for fuel cell vehicle commercialization. Toyota's fleet of conventional hybrids is expanding, and it has introduced an advanced diesel engine in Europe. Toyota hopes to sell 300,000 hybrids annually by 2005.



Toyota says commercial fuel cell vehicles will be based on hybrid technology.

Senior officials of the company were very optimistic about fuel cells during the 1990s, projecting at one point commercialization by 2003. Like most companies, Toyota is now much more guarded, asserting fuel cell vehicles will not be commercial before 2010.

Toyota has teamed with GM and Giner Inc., but it is not clear how closely the companies are working at present. Toyota has seen merit in selling small fuel cell electricity generators in an effort to bring down fuel cell development costs. Toyota has announced plans to sell a one-kilowatt residential unit in Japan.

Toyota is a member of the California Fuel Cell Partnership and is working with the University of California-Irvine and -Davis; the California Air Resources Board (CARB), South Coast Air Quality Management District (SCAQMD), and such corporations as Stuart Energy and Air Products to establish fully functional, fuel cell-friendly model communities in California. The communities will be linked by six hydrogen-refueling stations, including the one already open in Torrance, 40 miles northwest of the University of California-Irvine campus.

Toyota's Vision

Hiroyuki Watanabe, Senior Managing Director of Toyota, presented a sophisticated vision of the future of the automobile in 2003 at the Fuel Cell Seminar in Miami. Watanabe argued that exploding vehicle populations are a fundamental concern. He said no single technology would achieve the long-term energy efficiency and emission goals that must be achieved in the face of market expansion to remove vehicles from the pollution equation and open an era of truly sustainable mobility. But Watanabe argued that fuel cells hold the key, since they would allow fundamental redesign of vehicles, including the use of small, highly efficient wheel motors.

The FCV of the future thus could be simpler, smaller, and much lighter – perhaps 600 kilograms lighter — with no loss in customer amenities. Watanabe showed an animation of a highly stylized one-person vehicle.

Gallery

2002
FCHV (Kluger V/Highlander SUV)

FUEL TYPE
Compress. H_2 @5,000 psi
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
90 kW/PEM
FUEL CELL MANUFACTURER
Toyota
RANGE – >180 mi (300 km)
MPG EQUIVALENT – n/a
MAX SPEED – 96 mph (155 km/h)

2001
FCHV (Kluger V/Highlander SUV)

FUEL TYPE
Low-sulfur, clean gasoline (CHF)
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
90 kW/PEM
FUEL CELL MANUFACTURER
Toyota
RANGE – n/a
MPG EQUIVALENT – n/a
MAX SPEED – n/a

2001
FCHV-4 (Kluger V/ Highlander SUV)

FUEL TYPE
Compress. H_2 @ 3,600 psi
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
90 kW/PEM
FUEL CELL MANUFACTURER
Toyota
RANGE – 155 mi (250 km)
MPG EQUIVALENT – n/a
MAX SPEED – 95 mph (152 km/h)

2001
FCHV-3 (Kluger V/Highlander SUV)

FUEL TYPE
Hydrogen (stored in metal hydride)
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
90 kW/PEM
FUEL CELL MANUFACTURER
Toyota
RANGE – 186 mi (300 km)
MPG EQUIVALENT – n/a
MAX SPEED – 93 mph (150 km/h)

1997
RAV 4 FCEV (SUV)

FUEL TYPE
Methanol
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
25 kW/PEM
FUEL CELL MANUFACTURER
Toyota
RANGE – 310 mi (500 km)
MPG EQUIVALENT – n/a
MAX SPEED – 78 mph (125 km/h)

1996
RAV 4 FCEV (SUV)

FUEL TYPE	Hydrogen (stored in metal hydride)
ENGINE TYPE	Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE	20 kW/PEM
FUEL CELL MANUFACTURER	Toyota
RANGE	155 mi (250 km)
MPG EQUIVALENT	n/a
MAX SPEED	62 mph (100 km/h)

Volvo

Summary

Volvo's auto manufacturing facilities were sold to Ford in 1999, and Volvo now concentrates on the heavy-vehicle market. In 2002, Ford marketed about 400,000 vehicles carrying the Volvo badge. Volvo has been skeptical of fuel cells for light-duty vehicles, although it is involved in some European demonstrations and development work. Its NovaBus subsidiary is testing fuel cell buses.

Background

Volvo produced its first car in 1927. Volvo has pioneered the development of today's standard safety equipment, such as the safety cage, three-point seat belt, head restraint, ABS brakes, airbags, and the side impact protection system. Volvo makes heavy trucks, buses, and construction equipment, including Mack Trucks and Renault Trucks. Employment is about 77,000, and 2002 sales totaled $24 billion.

In 1996, Volvo and Volkswagen ordered $850,000 worth of fuel cells and test equipment from Ballard Power Systems.

In July 1998, Volvo released a report comparing a hybrid fuel cell/battery engine with a diesel engine; simulations were based on a Volvo 850, five-passenger car. The report asserted that the internal combustion engine was still ahead of the fuel cell when the total energy chain is considered. The report acknowledged this would change if the expected development of the fuel cell system is taken into account.

<u>Partnerships:</u>

1. VW, fuel cell vehicle development
2. Ballard, fuel cell equipment
3. Mazda
4. Ford
5. DaimlerChrysler

Development and Commercialization

Volvo was involved with the European Community's CAPRI project, partnering with Volkswagen to build a methanol-fueled PEM fuel cell hybrid vehicle. Volvo and VW are working together to produce a fuel-cell-powered golf cart.

Volvo's NovaBus subsidiary has demonstrated several fuel cell buses.

Volkswagen AG

Summary

Volkswagen is Europe's largest automaker. VW has built and tested several FCVs and a hydrogen combustion engine, but VW appears to be committed to commercializing advanced diesel engines and other high-efficiency combustion engines. Its hybrid 2002 HY POWER utilizes a German fuel cell stack and is unusual in using super capacitors as power boosters.

Vehicles and Characteristics

VW released its first FCV as part of the European Union's **CAPRI** project, partnering with Johnson Matthey (catalytic technology, fuel processing), ECN, Energy Research Foundation NL (electro-chemical engine), and AB Volvo Technological Development (compressor-expander unit, DC/DC converter, simulation work) to demonstrate a hybrid fuel cell electric vehicle. The fuel cell was provided by Ballard Power Systems.

The **Bora Hymotion** is based on the Jetta and is fueled by liquid hydrogen. It can reach speeds of 90 mph.

The Bora **HY POWER**, unveiled in 2002, is a hybrid that uses super capacitors to provide a power boost. The vehicle was tested over a Swiss mountain pass with good results. It utilizes a stack produced in Germany.

Background

Volkswagen has its roots in Germany between the World Wars. Ferdinand Porsche had the desire to develop an affordable car for the average German. By 1935, the first prototype Volkswagens ("people's car") were being road tested. Production began in 1946, initially to provide vehicles for occupying forces. The company put its first upgraded vehicles on the market about 1951. VW's U.S. division was formed in 1955. The VW Jetta and Golf (formerly Rabbit) have been available since the 1980s.

VW bought Auto Union, including the Audi badge, in 1964.

Volkswagen is the fourth-largest producer of passenger cars in the world and number one in Europe. The Volkswagen Group's annual sales approach 5 million units; sales revenue was about €87 billion in 2002. Volkswagen employs 280,000 workers worldwide.

Volkswagen has been involved in alternative fuels for about 30 years and has produced more than two million alcohol-fueled vehicles. VW's interest in electric vehicles dates to the late 1970s; VW put an electric version of its Golf on the market in Europe in the late 1990s and partnered with AC propulsion in California to produce a highly regarded Golf Electric. Volkswagen has two decades of experience working with hybrid drives.

VW showed its first fuel cell automobile in 1999 and its second in 2000. Both use Ballard engines. Its hybrid fuel-cell powered Bora HY POWER is unusual in using super capacitors capable of providing up to 30 kW of accelerating power. In 2002, the vehicle was tested over a Swiss mountain pass along with an advanced diesel-powered vehicle operating on a synthetic liquid hydrocarbon; the hybrid's performance was comparable with that of the diesel. It utilizes a stack produced in Germany.

Partnerships:

1. Volvo, methanol-fueled hybrid golf car
2. Paul Scherrer Institute, low-cost fuel cells and high-performance capacitors

Development and Commercialization

VW unveiled its first FCV at the California Fuel Cell Partnership in 2000, which suggests that at least in the early years, the fuel cell program was in part a defensive reaction to Daimler Benz's activism in fuel cells. VW has openly promoted advanced diesel and gasoline engines as the appropriate response to energy security and environmental concerns and has been a leader in selling light-duty diesel vehicles in the United States in recent years. VW is unlikely to be a leader in commercializing fuel cell vehicles.

VW is also promoting advances in synthetic fuels and has tested a hydrogen combustion engine.

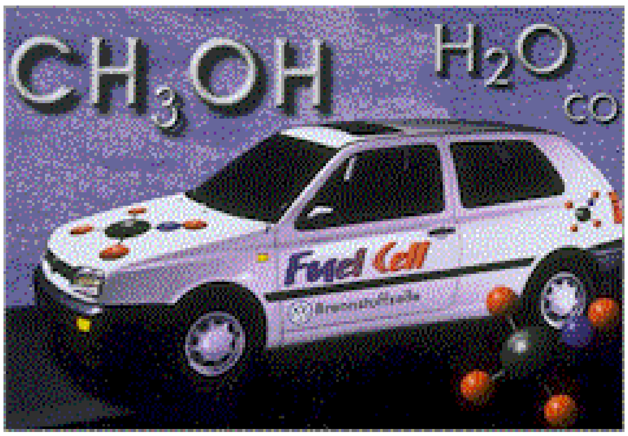
Gallery

2002
HyPower

FUEL TYPE
Compress. H_2
ENGINE TYPE
Fuel cell/super-capacitor hybrid
FUEL CELL SIZE/TYPE
40 kW/PEM
FUEL CELL MANUFACTURER
Paul Scherrer Institute
RANGE – 94 mi (150 km)
MPG EQUIVALENT – n/a
MAX SPEED – n/a

2000
HyMotion

FUEL TYPE	
Liquid hydrogen	
ENGINE TYPE	
Fuel cell	
FUEL CELL SIZE/TYPE	
75 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard	
RANGE – 220 mi (350 km))	
MPG EQUIVALENT – n/a	
MAX SPEED – 86 mph (140 km/h)	



1999–2000
EU Capri Project

FUEL TYPE	
Methanol	
ENGINE TYPE	
Fuel cell/battery	
FUEL CELL SIZE/TYPE	
15 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard Mark 500 Series	
RANGE – 155 mi (250 km))	
MPG EQUIVALENT – n/a	
MAX SPEED – n/a	

Fuel Cells in Transit Buses

Summary

Transit buses are widely viewed as one of the best strategies for commercializing fuel cells for vehicles and transitioning to a hydrogen economy. Many advantages have been identified regarding the use of transit buses as fuel cell platforms. For example:

- Transit buses have well-defined duty cycles, centralized fueling and maintenance infrastructure, and dedicated maintenance personnel;
- Transit buses are large, providing ample room to install the fuel cell and related components;
- Diesel transit buses are noisy and polluting, providing fuel cells with an opportunity to make significant performance improvements;
- Transit bus manufacturers generally do not develop their own power plant technologies, not even diesel engines. Thus, they are accustomed to working with power plant manufacturers to accommodate new technologies;
- Transit agencies are subsidized by the government, thus helping to defray most of the risks and costs of technology development;
- Transit buses are highly visible in the community, providing an excellent showcase for fuel cells; and
- Fuel cell transit technology can readily be transferred to other medium- and heavy-duty vehicle applications.

As a result, governments in North America, Europe, and Asia are supporting many demonstrations of fuel cell buses, causing the number of fuel cell buses to grow at an almost exponential pace. In 2003 alone, the number of fuel cell buses built and operated doubled, bringing the total to around 65 worldwide. The demonstrations are designed to prove the technology in revenue service and collect data on operations and maintenance costs, performance, and reliability.

Nearly all of the modern buses are powered by PEM fuel cells. PEM fuel cells appear to offer advantages in transportation applications, including high power density, low temperature operation, quick start-up, rapid response to varying loads, and the ability to use inexpensive manufacturing materials. Power output can be greater than 200 kW.

Nearly all use compressed hydrogen as fuel, typically stored in high-pressure tanks mounted on the roof of the vehicle. This allows the hydrogen to be produced off-vehicle, thus reducing the vehicle's cost, weight, and complexity. This storage system also uses technology similar to that used for compressed natural gas, which is well known within the transit industry. Refill time for compressed hydrogen tanks is similar to that of gasoline tanks.

The roof mounting also appears to offer advantages. The small size of the hydrogen atom makes storage systems more likely to leak than storage systems for other fuels. The roof mounting enables the hydrogen to quickly dissipate into the atmosphere, if a leak should occur. Moreover, the roof of the bus is very unlikely to be damaged in the event of a traffic collision, thus helping to ensure the integrity of the tanks.

Demonstrations

Currently, most fuel cell buses are in Europe. The European Union's (EU's) Clean Urban Transport for Europe (CUTE) project is responsible for 30 fuel cell buses in nine European cities and Iceland. Three additional buses are scheduled for operation in Perth, Australia, in 2004. Similarly, the EU's CITYCELL program seeks to operate four fuel cell hybrid buses in Madrid, Berlin, Paris, and Turin.

Other countries also appear to have significant plans for fuel cell buses. China intends to use up to 100 fuel cell buses at the 2008 Beijing Olympics. The United Nations is supporting the deployment of more than 40 fuel cell buses in various cities. There also are plans to use Toyota/Hino fuel cell buses at the 2005 World Exposition in Japan. (See additional discussion in the chapter on government-sponsored demonstrations.)

In North America, fuel cell buses have been or will be tested in a number of areas. These include:

- Six buses tested Chicago and Vancouver between 1998 and 2000.
- The planned 2004 demonstration of seven fuel cell buses by the California Fuel Cell Partnership. Three buses will be manufactured by Gillig and deployed in the Santa Clara Valley, California. Four buses will be manufactured by Van Hool and deployed by AC Transit and Sun Line transit.
- A proposed demonstration of zinc-air fuel-cell-powered buses in Las Vegas.
- The planned acquisition of fuel cell buses by Dallas Area Rapid Transit.
- Potential extension of Georgetown University's fuel cell bus program into a third generation, using a 40-foot bus platform, a PEM fuel cell, and methanol.
- A three-year project by Natural Resources Canada to develop and deploy new hybrid fuel-cell bus technology. The bus will have a 180-kW PEM fuel cell and a regenerative braking system.
- A coalition, known as the National Fuel Cell Bus Technology Initiative (NFCBTI), is proposing to allocate $150 million in U.S. federal transportation funding for fuel cell bus development and deployment. Members include AC Transit, Ballard, Boeing, the CEO Coalition to Advance Sustainable Technologies, ECD Ovonics, Hydrogenics, ISE Research, the Northeast Advanced Vehicle Consortium (NAVC), Quantum Technologies, Sun Line Transit, Texaco Ovonic Hydrogen Systems, Thor Industries, and the Tri-Metropolitan Transportation District of Oregon (TriMet).

A summary of some of the most significant fuel cell bus projects and programs follows.

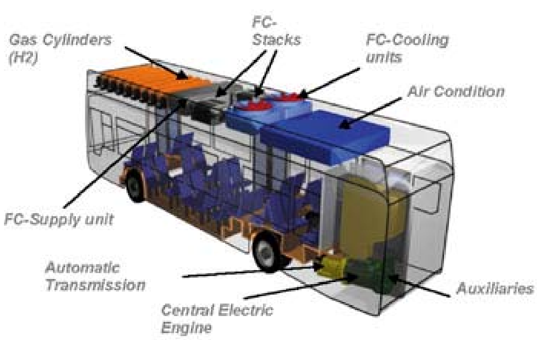
DaimlerChrysler

DaimlerChrysler's EVOBUS has developed three generations of fuel cell buses. The first generation was the Nebus (No Emissions Bus), introduced by Mercedes-Benz in 1997. It accumulated more than 540 driving hours in Norway and Germany. Next was the Zebus (Zero Emission Bus), developed in 1999 with Sun Line Transit. It was demonstrated for 13 months in Palm Desert, California, acquiring almost 15,000 miles.

The latest bus, the Citaro, is being tested in Europe. The Citaro was introduced in 1997 as a diesel urban transit bus. It is a low floor design with three doors, capable of carrying roughly 60 passengers.

The modified fuel cell versions contain a 200-kW fuel cell, which the company says enables performance comparable with that of a diesel. The buses use compressed hydrogen fuel contained in a storage module located on the roof. There are nine 205-liter high-pressure cylinders.

The Citaro is being delivered to nine European cities under the CUTE program. Three more Citaro buses are being operated in Iceland under the Ecological City Transport System (ECTOS) project, and another three will be delivered to Perth, Australia, through their Sustainable Transport Energy Program (STEP). The vehicles will be tested and evaluated for two years.



In addition to fuel cell technology, EVOBUS has other innovations, such as automatic lane recognition, electronically controlled brake applications, distance regulated cruise control, and improved vision with infrared light.

Company Information

EVOBUS was established in 1995 when Sentra merged with Mercedes-Benz. EVOBUS is now part of the DaimlerChrysler group. EVOBUS is the leading full-time supplier of European bus and coaches.

Irisbus

Irisbus is participating in the European Union's CityCell program. This program is designed to demonstrate five fuel cell hybrid vehicles in Turin, Berlin, Madrid, and Paris. Three of those buses will be produced by Irisbus.

Irisbus has begun passenger service with one fuel cell bus in Torino and is testing a fuel cell bus in Madrid.

The Madrid bus is a 40-foot Cristalis hybrid fuel cell vehicle powered by a 62-kW PEM fuel cell developed by United Technologies Corporation. The bus will include a step-up converter and electric drive train made by ANSALDO, a lead-acid battery energy storage system, and a compressed hydrogen storage system in nine cylinders.

Company Information

Irisbus was established in January 1999 with the union of the Fiat-Iveco Group and the Renault Group, which merged their coach and bus divisions.

Gillig

Gillig plans to deliver three low-floor fuel cell buses to the Santa Clara Valley Transportation Authority (VTA) in 2004. The buses will be operated in real-world conditions and will include such features as air conditioning, a ramp for ADA accessibility, destination signs, and an audio system to identify bus stops. The buses will operate for two years in San Jose through a joint demonstration program with VTA, the San Mateo Transportation District, the California Fuel Cell Partnership, and the California Air Resources Board.

The buses will be powered by 205-kW Ballard fuel cells using compressed hydrogen fuel. Fueling will be done on-site by using a 9,000-gallon liquid hydrogen storage tank and dispensing system. Each bus can be filled in 10 to 12 minutes.

The program will evaluate fuel cell technology and examine or advance maintenance, performance, costs, fueling safety, employee training, and public education and awareness.

The total program budget is $18,450,000. This includes $10,565,000 for the buses and $3,103,000 for facilities.

Company Information

Gillig has evolved over the past 110 years from a buggy and carriage manufacturer in San Francisco to a national company that builds heavy-duty transit buses. Gillig produces two basic models: the standard floor model called the Phantom and a newer Low Floor model. Gillig is the second largest producer of transit buses in North America and produced more than 1,200 buses in 2000 for almost l00 different customers, from Alaska to Florida.

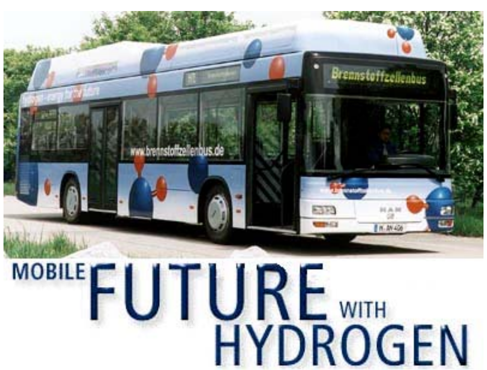
MAN

In 2000, MAN unveiled a 40-foot fuel cell bus developed by various industry partners and funded largely by the Bavarian State Ministry for Economic Affairs, Transport, and Technology. The bus is based on a MAN model NL 263 low-floor bus. It uses four Siemens PEM fuel cell modules that can deliver a net electrical output of 120 kW. The power is delivered to two electrical motors rated at 75 kW each. Compressed hydrogen fuel is stored in nine Dynetek cylinders mounted on the roof. The cylinders hold enough hydrogen to provide a range of roughly 150 miles.

The vehicle was demonstrated in public revenue service for six months in late 2000 and early 2001, accumulating nearly 5000 miles of service.

Passenger response was overwhelmingly positive. Drivers reported no difference between the fuel cell bus and a typical diesel bus. The technical issues identified by the demonstration included the need to reduce weight, improve the size and installation of the fuel cells, reduce operating costs (which were inflated mainly due to the costs of producing and supplying the hydrogen), and use a hybrid system to recapture energy and reduce fuel consumption.

In May 2003, MAN and Ballard Power Systems announced an agreement to build a hybrid fuel cell bus to be used at the Munich Airport beginning in 2004. The low-floor bus will be powered by a 65-kW PEM fuel cell system and compressed hydrogen fuel, which will be stored in rooftop tanks. The bus will have a regenerative braking system.



MAN is part of the Clean Energy Partnership Berlin (CEP). CEP was established in 2002 to test the viability of a hydrogen-based economy and is subsidized by the German government.

MAN buses are part of THERMIE, a program to supply liquid hydrogen fuel cell buses to Lisbon, Copenhagen, and Berlin. Because of technical problems with the fuel cell, the bus has not yet been placed in operation.

Company Information

MAN is one of Europe's leading suppliers of commercial vehicle parts and mechanical and plant engineering. Created in 1986, MAN employs 75,000 people in five divisions.

NABI (North American Bus Industries)

NABI's Model 40C-LFW and Model 45C-LFW composite buses were specifically designed to use hybrid and fuel cell power. Currently, NABI is working with the Sun Line Transit District of Palm Springs, California, to install a fuel cell power system in its 45-foot, Model 45C-LFW bus, pictured at the right. The bus will use a 170-kilowatt cell from United Technologies Corporation. The bus also will use regenerative braking and either batteries or an ultracapacitor to provide acceleration and extra power for hills.

The bus will be evaluated in the extreme heat of Palm Springs. Sun Line also will compare the reliability of the fuel cell bus to its existing CNG.

The bus initially will be delivered as a CNG vehicle to ISE Research, a San Diego-based engineering firm. ISE will install the UTC fuel cell and a Siemens ELFA hybrid-electric drive system. ISE also will adapt the high-pressure CNG storage tanks to store compressed hydrogen. The tanks are located on the roof of the bus.

Sun Line already operates a hydrogen refueling facility through the California Fuel Cell Partnership.

Company Information

NABI assembles and offers post-delivery support on a full range of heavy-duty diesel, compressed natural gas (CNG), and liquefied natural gas (LNG) transit buses. NABI, Inc., is a wholly owned subsidiary of NABI Rt., which was incorporated in Hungary in 1992.

NABI's headquarters and manufacturing facilities are in Anniston, AL. These facilities include two bus assembly plants, offices, and a research and development center. This facility receives bus bodies from NABI, Rt., and conducts final assembly.

Neoplan

Neoplan's main fuel cell product is the Midibus N8008FC, a small bus designed for cities and resorts. These buses are based on Neoplan's original low-floor compact bus design and have a maximum capacity of 47 passengers, with 12 sitting and 35 standing. They have been operating at a spa in the German city of Oberstdorf since 1999.

The bus is powered by a 3-stack, 40-kW PEM fuel cell and a battery with a 21-kW storage capacity. It has water-cooled electric drive motors that serve as regenerative brakes. The fuel cells use compressed hydrogen fuel stored in four roof-mounted carbon fiber tanks. The range is roughly 600 km.

Neoplan also displayed a hybrid PEM fuel cell bus in May 2000. This vehicle was powered by an 80-kW PEM fuel cell and a 100-kW flywheel system to provide additional power for hills and acceleration.

Company Information

Neoplan was founded under a different name in 1935 in Stuttgart, Germany. In 1953, the Neoplan brand was introduced, and since that time, over 35,000 Neoplan buses have been sold.

Neoplan opened U.S. manufacturing operations in 1981. It currently operates several manufacturing facilities in Germany and the United States.

New Flyer Industries

New Flyer produces a full line of vehicles that use a variety of fuels, including compressed natural gas (CNG), liquefied natural gas (LNG), and diesel hybrid-electric.

A New Flyer bus was used for the first fuel cell bus in 1993. It had a 90-kW PEM fuel cell and used compressed hydrogen fuel.

Between 1997 and 2000, three New Flyer fuel cell buses were tested in Chicago and Vancouver. The buses racked up more than 73,000 miles. All the buses used Ballard fuel cell systems.

In 2002, the Government of Canada and Hydrogenics Corporation announced a new hybrid fuel cell transit bus project that will use a Hydrogenics fuel cell mounted in a New Flyer bus. The bus will be demonstrated in Winnipeg and possibly other Canadian cities. This project is scheduled to conclude in 2005. The project will use vehicle-to-grid technology developed by Hydrogenics. This technology enables the vehicle, while sitting idle, to supply power off-board and to the electrical grid. The bus itself will feature ultracapacitors for the regenerative braking system. The ultracapacitors will be supplied by Maxwell Technologies. The vehicle will use compressed hydrogen fuel. The vehicle will have several fuel cell stacks producing a total of 180 kW, rather than a single stack. This will enable the weight to be distributed more evenly and may result in greater flexibility for both grid and road power.

The project has a total cost of approximately CAN$8 million, with Natural Resources Canada (NRCan) contributing CAN$2 million during the first phase and CAN$1 million to the second. Hydrogenics and its partners are contributing the remainder.

System development is scheduled to conclude in March 2004, followed by system integration and on-road testing at Winnipeg Transit (March 2004–2005).

Company Information

New Flyer is the largest transit bus manufacturer in North America. The company began in 1930 by building truck and bus bodies. In the late 1960s, the company focused upon transit buses, quickly becoming the nation's leading trolley bus manufacturer. In 1986, the company was acquired by Holland's largest bus manufacturer. New Flyer of America was established in 1987 to operate a U.S. assembly plant. Currently, New Flyer has production facilities in Winnipeg, Canada; Crookston, Minnesota; and St. Cloud, Minnesota.

Nova Bus

The U.S. government has, since 1983, funded research into fuel cells for transit buses, based at Georgetown University in Washington, D.C. The program began with the development of three 30-foot transit buses (see discussion above). The Federal Transit Administration in 1993 began funding a program to demonstrate the commercial viability of fuel-cell-powered transit buses via construction and operation of two 40-foot hybrid fuel cell buses.

Both buses were developed on the basis of a wide-door, 40-foot platform manufactured by Nova Bus. Each vehicle uses a 100-kW fuel cell coupled with a battery pack and regenerative braking.

One vehicle uses a methanol-powered phosphoric acid fuel cell manufactured by United Technologies Corporation. It features an electric drive train developed by BAE Systems Controls. Booz·Allen & Hamilton, Inc., served as systems integrator and developed the vehicle's system controller.

The second vehicle uses a methanol-powered PEM fuel cell manufactured by XCELLSiS.

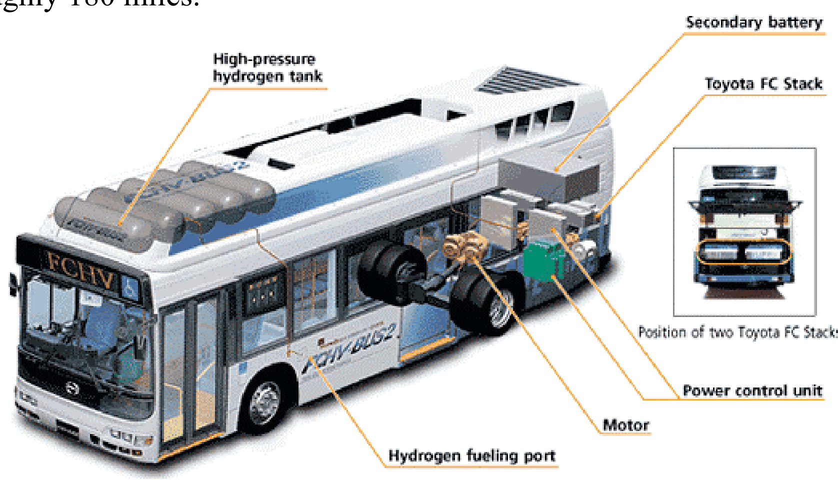
Company Information

Nova Bus was founded in 1993 through the acquisition of the MCI bus manufacturing plant in Saint-Eustache, Quebec. In 1998, Nova Bus was acquired by Prevost Car, Inc., a joint subsidiary of Volvo Bus Corporation and Henlys Group PLC. Currently, Nova Bus operates both a manufacturing facility and an assembly facility in Quebec, Canada.

Toyota

In 2001, Toyota unveiled **FCHV-BUS1**, a low-floor, fuel cell hybrid based upon on a Hino Motors low-floor city bus. The vehicle used a 90-kW fuel cell developed by Toyota with nickel-metal hydride batteries and regenerative braking. The bus used compressed hydrogen fuel stored on the roof and had a range of roughly 180 miles.

In 2002, Toyota announced an improved version, called the **FCHV-BUS2**. This version uses two of the Toyota 90-kW fuel cell stacks and the hybrid drive system. It has two motors with a maximum output of 80 kW each and a maximum torque of 260 Nm each. Like its predecessor, this bus uses compressed hydrogen fuel.



The bus entered revenue service in Tokyo in August 2003. It has a maximum capacity of 60 passengers.

In 2005, Toyota plans to have an improved version of the FCHV-BUS2 operating at Expo 2005 in Aichi, Japan. The vehicles are expected to carry roughly 1,000 passengers per hour on a two-mile run at the EXPO.

Company Information

Toyota Motor Corporation was spun off from Toyoda Automatic Loom Works in 1937. Toyoda had entered the vehicle business a few years earlier. Toyota entered the industrial vehicle market in 1956. It merged with Hino Motors, maker of trucks and buses, in 1966

Thor Industries, Inc.

Thor Industries, Inc., created a joint venture with ISE Research Corp. called ThunderPower. In 2001, Thor received a $740,000 grant from the U.S. Department of Transportation to develop and demonstrate a hybrid fuel cell transit bus.

In 2002, Thor's 30-foot transit bus, known as the "ThunderPower," went into operation with the Sun Line Transit Agency. It became the first fuel cell hybrid bus to enter passenger service in California.

The ThunderPower is powered by a 75-kilowatt UTC PEM fuel cell. The fuel cell produces electricity to both propel the bus and charge the batteries. The ThunderPower also has regenerative braking.

The ThunderPower uses compressed hydrogen fuel. Its gasoline-equivalent fuel efficiency is double that of a conventional bus. It has a maximum range of 175 to 200 miles and can carry 26 passengers.

The bus uses a drive system by ISE-TVI ThunderVolt. It features a dual motor/controller set that has a continuous power rating of 170 kW and a peak power rating of 288 kW. It also features a systems integration system developed by ISE-TVI.

Company Information

Thor Industries, Inc., was founded in 1980 when Wade F. B. Thompson and Peter B. Orthwein acquired Airstream, a recognized name in the industry. In 1982, Thor incorporated General Coach. Thor became a public corporation in 1984. With more than 4,000 employees, Thor is the largest mid-sized bus builder and the second largest RV manufacturer.

Van Hool

Van Hool has been involved with fuel cell buses for more than a decade. In the mid-1990s, Van Hool participated in the development of an 18-meter, articulated bus powered by an alkaline fuel cell. The bus, which was demonstrated in Brussels, used liquid hydrogen fuel. The fuel cell produced roughly 78 kW and was augmented by batteries.

Currently, Van Hool is building four of the seven fuel cell buses being evaluated through the California Fuel Cell Partnership. ISE Corporation of San Diego will design and build the hybrid drive system and serve as a system integrator. UTC will supply the fuel cell engines.

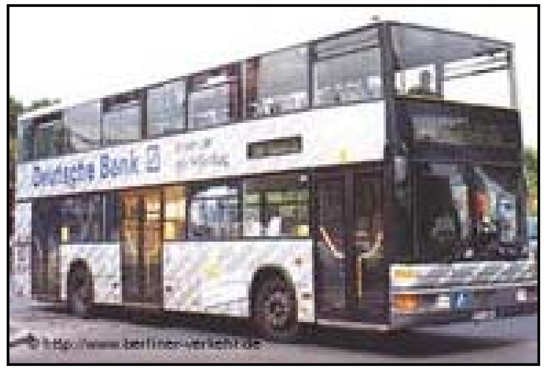
The buses will be based upon Van Hool's Model A330, which was awarded "Bus of the Year" in a recent competition with other European bus manufacturers. The bus includes a variety of innovative features, including a continuous low floor, three wide doors, spacious interior, panoramic side windows, and modern internal/external passenger information displays.

Three buses will be owned and operated by AC Transit. The vehicles will be evaluated to compare their performance with diesel buses. Sun Line Transit will own and operate the fourth bus. Delivery currently is scheduled to begin in September 2005.

Company Information

Bernard Van Hool founded the company in Belgium in 1947. The company currently produces thousands of vehicles annually and is the second largest manufacturer of transit buses in Europe.

Volvo Bus



Volvo bus is working with Germany's largest urban transport operator, the Berliner Verkehrsbetriebe (BVG), to put two double-decker fuel cell buses into operation in Berlin. These will be the first double-decker fuel cell buses in the world.

The buses will be powered by PEM fuel cells developed by Proton Motor, a German fuel cell manufacturer. They will be 50 feet long and carry between 120 and 130 passengers, most of them seated.

This will be Berlin's second attempt to introduce fuel cell buses. The first effort faltered due to problems with the fuel cell technology, which was produced by transportation giant MAN.

Company Information

The Volvo Group is one of the world's leading manufacturers of trucks, buses, construction equipment, drive systems, and aerospace components and services.

Founded in 1927, Volvo has roughly 72,000 employees. It has production operations in 25 countries and operates on more than 185 markets.

Specialty Vehicles

History

The first fuel cell vehicles were specialty vehicles.

Allis Chalmers built and demonstrated a tractor in 1959 utilizing an alkaline fuel cell that produced 20 horsepower.

During the 1960s, Pratt & Whitney delivered the first of an estimated 200 fuel cell auxiliary power units for space applications. Union Carbide delivered a fuel cell scooter to the U.S. Army in 1967.

PEM fuel cells were invented in the 1960s for military applications and have been used since the 1970s in submarines.

Allis Chalmers fuel cell tractor, 1959

Engelhard developed a fuel-cell-powered forklift about 1969.

Since fuel cells are modular, scalable, and fuel-flexible, they remain excellent candidates for a wide range of specialty vehicle applications. Fuel cells are currently being demonstrated on land, in the sea, and in the air.

Bicycles and Scooters

Fuel cell bicycles and scooters are being developed for markets in Europe and Asia. Densely populated cities, particularly in India, rely heavily on bicycles and scooters for personal mobility. There are an estimated 100 million motorized two-wheel vehicles in use worldwide. These vehicles are inefficient and polluting. In Bangkok, scooters produce more hydrocarbon and particulate emissions than buses, trucks, and cars combined.

Electric bicycles are becoming more and more popular, in part as a result of government incentives and restrictions on two-stroke engines. Major Asian cities, such as Shanghai, have recently adopted policies to phase out gas mopeds and bicycles. Most companies working on fuel-cell-powered scooters project market introduction in 2004, although that target appears very ambitious.

Asia Pacific Fuel Cell Technologies

Asia Pacific Fuel Cell Technologies (APFCT) showcased a proof-of-concept Zero Emission Scooter (ZES) scooter in April 2000, working with Kwang Yang Motor Co., Taiwan, Taiwan Institute of Economic Research, and the W. Alton Jones Foundation. The scooter's development began at the Desert Research Institute (DRI).

The second-generation scooter, the ZES II, appeared in November 2000. The ZES III was redesigned from the ground up and debuted in July 2002. It uses an APFCT 1-kW PEM fuel cell stack. ZES III has a top speed of 58 km/hour and a range of 120 km at 30 km/hour. A pre-commercial prototype, the ZEV IV, was completed in September 2003. It weighs 109 kg.

APFCT, DuPont Fuel Cells and DuPont Taiwan, Ltd., have agreements in place to commercialize PEM fuel cells for the Taiwan electric scooter market by 2005. The Taiwan Institute of Economic Research is exploring infrastructure options, such as collecting and refilling pressurized hydrogen canisters at 7-11 or Super K stores.

Palcan Fuel Cells Ltd.

Palcan Fuel Cells is developing small fuel cells (100 W and 5 kW power range) for bikes, scooters, and forklifts. Palcan and Shanghai Forever unveiled a fuel cell bicycle at the Asia Pacific Economic Cooperation (APEC) TechnoMart Exhibition in China.

In 2000, Palcan established Shangai Palcan Fuel Cell Ltd. with three Chinese partners to develop a Chinese market for fuel cells. Palcan's marketing strategy is to enter joint venture agreements with OEM's worldwide, providing access to system integration, manufacturing, sales, and distribution and service capability. In 2001, Palcan signed a memorandum of understanding (MOU) with both the Chuang Yuan Group Company, Ltd., and Shanghai Forever Company, Ltd., for the manufacturing and integration of Palcan's PalPac portable fuel cell system into electric bicycles and motor scooters.

Palcan Fuel Cells has successfully integrated its 2 kW fuel cell system into a scooter, using its own metal hydride hydrogen storage technology.

PEM Technologies, Inc.

PEM Technologies, Inc., is focusing on small- to medium-size fuel cell power systems (<10 kW) for portable power, light/personal electric vehicles, and non-road industrial electric vehicles. In July 2002, PEM Technologies introduced the PemPower-02, a PEM fuel cell scooter, and in 2003 unveiled the PemPower-03, a two-wheel motorcycle and the PemPower-04, a three-wheel motorcycle. The range for both the 03 and 04 was increased by more than half.

Manhattan Scientifics

In 2003, Manhattan Scientifics, Inc., issued a non-exclusive patent license of its NovArs mid-range fuel cell technology to Ballard Power Systems, providing unlimited use rights to Ballard for its proprietary technology and systems.

In 1999, Manhattan Scientifics acquired global intellectual property rights to the advanced fuel cells, materials, and concepts technology of NovArs and is working with Italian bicycle manufacturer Aprilia to incorporate units made by NovArs into scooters and bicycles.

Its most recent prototype was shown in 2002. The Mojito FC uses a Manhattan Scientifics/NovArs 3-kW PEM fuel cell stack fueled by compressed hydrogen. Top speed is 35 miles per hour, and the range is 120 miles.

The fuel cell bicycle made by Manhattan Scientifics, designed by Aprilia S.p.A. with a NovArs fuel cell, was named one of Time Magazine's "Inventions of the Year" in 2001. The bicycle stores compressed hydrogen in a 2-liter canister in the frame and has a range of about 50 miles and top speed of 20 miles per hour.

Prior to working with Aprilia, Manhattan Scientifics released the Hydrocycle, a fuel-cell-powered concept bicycle. The hydrogen fuel is stored in a 2-liter carbon fiber pressure vessel located behind the seat. The bicycle has a range and top speed comparable with those of the initial Aprilia unit.

Other Developers

Yamaha Motor Company has developed a fuel cell for motorcycles, powered by methanol. Yamaha is also working with battery maker Yuasa Corporation to develop fuel cells for 50 cubic centimeter (cc) -class motor scooters. A prototype reached 40 kilometers per hour (25 mph), with an output of 500 watts, which is generally equal to the performance of standard 50-cc scooters.

With support from the South-North Institute for Sustainable Development (SNISD), **Beijing Fuyuan Century Fuel Cell Power Ltd.** has joined forces with Suzhou Small Antelope Bicycle Company and jointly manufactured a fuel-cell-powered scooter in China.

Golf Carts/Forklifts/Utility Vehicles

Astris Energi, Inc.

Since 1983, Astris Energy has been pioneering the development of alkaline fuel cell electric generators and now has three such power systems "fully tested and ready for commercialization." Astris is concentrating on 1-5 kW systems.

Astris unveiled its first fuel-cell-powered golf cart in 2001. The fuel cell runs on compressed hydrogen gas — enough for more than three days on the golf course or about eight hours of continuous driving. The golf cart has a maximum speed of 25 mph and a range of more than 250 miles.

Astris Energy's principal strategy is to form joint ventures with leading manufacturers of golf carts and recreational vehicles. Astris recently terminated its agreement with Care Automotive, Inc.

Astris also manufactures a 4-kW fuel cell, which it hopes to market as a generator for recreational vehicles. The 4-kW unit can also be incorporated into yachts and boats.

Deere & Company

Deere & Co. has purchased six Hydrogenics 10-kW HyPM-LP2 fuel cell power modules for integration and evaluation in off-road vehicles, including grounds equipment and utility vehicles. The collaboration produced a prototype (Deere's second) in 2003 — a modified John Deere Pro-Gator™ Utility Vehicle. The Gator has a speed of 50 km/hour and a range of "four hours." It is currently being demonstrated across the United States.

Deere & Co. is also part of a consortium of technology and end-user partners planning to develop, demonstrate, and "pre-commercialize" fuel-cell-powered forklifts.

Sustainable Development Technology Canada (SDTC) has approved a proposal to outfit two Class-1 forklifts with 10-kW fuel cell propulsion systems and metal hydride hydrogen storage systems, develop fueling infrastructure, gather market information, and demonstrate the forklifts to industrial end users. Consortium members also include Hydrogenics, FedEx Canada, General Motors of Canada, HERA Hydrogen Storage Systems, NACCO Materials Handling Group, and the City of Toronto.

Siemens/KWU demonstrated a fuel-cell-powered forklift several years ago. The 10-kW PEM fuel cell uses hydrogen, stored in titanium-based hydride tanks. The tanks hold 23 standard cubic meters of gaseous hydrogen, which is enough to run the forklift for eight hours.

Locomotives

The **Fuelcell Propulsion Institute** in Colorado built a fuel-cell-powered mine locomotive using a Nuvera PEM fuel cell stack. It has been working in regular mucking operations since October 2002 in Ontario and has performed well, pulling five loaded cars (20 tons) without difficulty.

The Fuelcell Propulsion Institute is also part of an international consortium funded by the U.S. Army National Automotive Center (NAC) to develop and demonstrate a 109-metric ton, 1-mW fuel cell locomotive for military and commercial railway applications. Plans call for refitting a 1,200-horsepower switch engine with a fuel cell. Funding for Phase 1 of the five-year project is $1 million.

Boats, Yachts, Submarines

Marine engines are among the highest contributors of hydrocarbons (HC) and nitrogen oxides (NO_x) emissions in many parts of the world. An outboard motor can produce more than 100 times the emissions of the average car per hour of operation. An increasing number of lakes in Europe and the United States ban motor boating. Fuel cells are being evaluated as an alternative engine for boats.

A report by John J. McMullen Associates, Inc., concluded that the marine market potential (commercial and military) for fuel cells could be tens of thousands of units by 2015.

MTU Friedrichshafen unveiled the first fuel cell powered yacht, with a propulsion system manufactured by Ballard Power Systems.

The 12-meter- yacht, named "No. 1," will operate in Lake Constance in Kressbronn, Germany.

A hydrogen-fueled public water taxi, powered by an Anuvu Power-X fuel cell/battery electric hybrid engine, was demonstrated at the World Maritime Technology Exposition in San Francisco. The 18-passenger boat was funded by California's Center for the Commercial Deployment of Transportation Technologies, with Seaworthy Systems, Duffy Electric Boat, and Millennium Cell involved as project partners.

HaveBlue is developing hydrogen systems for recreational sailboats and powerboats. The company has begun testing components aboard the X/V-1, a specially-built 42-ft Catalina model 42 Mk. II sailboat, provided by sponsor Catalina Yachts. The boat is being fitted with a self-contained, onboard, zero- or ultra-low-emission power system that may utilize fresh or saltwater and electricity from renewable technologies to produce, store, and consume hydrogen as fuel.

A fuel-cell-powered U 31 submarine, developed by **Howaldtswerke-Deutsche Werft AG**, has begun testing in the western Baltic Sea. Tests are expected to continue into 2004.

Siemens AG has agreed to supply the Greek Navy PEM modules for use as APUs/range extenders in three class 209 submarines, with an option for a fourth unit. Siemens will supply the fuel cell modules, control and monitoring systems, control cubicles, control gear, and material packages to modernize the existing electrical equipment. Delivery is scheduled to begin in 2004.

Airplanes — NASA and Boeing

NASA

The National Aeronautics and Space Administration (NASA) conducted a feasibility study of fuel cells for aviation. The study found that a fuel-cell-powered craft was capable of a 140-mile flight carrying 270 pounds, with current state-of-the-art components. Fuel cells are an attractive option for aviation since they produce zero or low emissions and make barely any noise. The military is especially interested in this application because of the low noise, low thermal signature, and ability to attain high altitude.

Boeing

Boeing plans to test a fuel-cell-powered airplane in late 2004 or early 2005. The project will be led by Boeing's Research and Technology Center in Madrid, Spain. Other partners include Advanced Technology Products, Diamond Aircraft, Sener, and Aerlyper. The plane will be a modified version of Diamond's Katana Xtreme Motorglider, also known as the Super Dimona, running on a fuel cell, batteries, and an electric motor. The craft will have room for only one pilot, with some cockpit space taken up by the fuel cell.

Boeing strongly believes fuel cell auxiliary power units, or APUs will become a viable option for generating electricity while jetliners are on the ground, powering air conditioners and controls. Today's turbine APUs generate significant emissions.

Boeing has established a team of researchers working on a solid oxide fuel cell (SOFC) APU that will use Jet A fuel. Fuel efficiency of the fuel cell could save up to 40% of fuel during a flight.

Boeing is also designing a fuel-cell-propulsion system for a new unmanned aerial vehicle (UAV), under the Pentagon's Defense Advanced Research Projects Agency (DARPA) program.

NASA's Glenn Research Center has awarded a $524,999 contract to **Advanced Technology Products** of Worcester, Massachusetts, to design and build a fuel cell power system for a high-performance composite electric-propelled aircraft. Advanced Technology Products is also working on a two-seater fuel cell electric plane (E-Plane) with funding from both NASA and FASTec (Foundation for Advancing Science and Technology Education Curriculum).

The first flights ran on rechargeable batteries; the Phase II flights will be powered by a combination of Lithium Ion batteries and a hydrogen fuel cell. In Phase III, the aircraft will be powered totally by the fuel cell, with a range of more than 500 miles. The E-Plane is based on a high-speed, carbon composite DynAero Lafayette III, built and donated by American Ghiles Aircraft. The project is due for completion by 2004.

AeroVironment has been working with PEM fuel cells to provide nighttime power for its solar-powered unmanned NASA Helios aircraft. The goal is to make the Helios fly continuously for up to six months; during the day, the aircraft would have photovoltaic panels that run electric motors and electrolyze water into hydrogen. At night, the fuel cell would run the motors, converting the hydrogen and oxygen back into water.

Unfortunately, the Helios flying wing was destroyed when it crashed into the Pacific Ocean just 29 minutes into a functional checkout flight. NASA has formed an accident investigation team to determine the exact cause of the crash, and an interim status report by NASA's Mishap Investigation Board (MIB) reveals that the Helios experienced "undamped pitch oscillations," which led to a partial breakup of the aircraft at 3,000 feet.

The fuel cell system had not yet been turned on when the disaster occurred.

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ED01-0230-1 Date: August 13, 2001 Photo by: Nick Galante
NASA's Helios Prototype aircraft taking off from the Pacific Missile Range Facility, Kauai, Hawaii, for the record flight.

Appendix A: Study Details

Contractor

Breakthrough Technologies Institute
1625 K Street, NW
Suite 725
Washington, D.C. 20006
Phone: (202) 785-4222; Fax: (202) 785-4313
Project Managers:
Jill Buckley: e-mail: jillb126@aol.com
Robert Rose: e-mail: brose@fuelcells.org

DOE Program Manager: Donna Ho (202) 586-8000

Subcontractors

Alfred Meyer, West Simsbury, CT
World Fuel Cell Council, Frankfurt, Germany
David Hart, London, England
Dr. Ji-Qiang Zhang, Charlottesville, VA
Robert Wichert, Citrus Heights, CA

Objectives

- Research, assess, and evaluate the current status, strategies, policies, and future plans of governments, major energy companies, major motor vehicle manufacturers, and developers of key components of fuel cells designed for use in motor vehicles in countries outside the United States;
- Attempt to measure the technical progress of companies in international markets against DOE's targets and goals; and
- Assess the commercialization plans of companies and government programs to support commercialization and evaluate them against the team's own experience and expertise.

Approach

- Step 1. Review existing and/or ongoing studies and available information on the status of development in major international markets. Define parameters of survey and develop criteria for selecting participants.
- Step 2. Develop lists of potential respondents. Build separate lists for each sector to be surveyed: automobile manufacturers, major component companies, energy corporations, and governments. Divide lists by region (Japan/South Korea, China/Taiwan, Western Europe, Canada, and other).

Divide lists by survey method (site visit, phone interview, mailed questionnaire).

- Step 3. Develop survey instruments/interview guides. Create separate questionnaires for each sector and each method (12 questionnaires total).
- Step 4. Conduct site visits. Form four teams, each led by a consultant accompanied by DOE personnel, to visit top priority companies and government officials in July 2002.
- Step 5. Refine lists and contact phone and mail respondents. Provide up-to-date written DOE briefing to each respondent. Follow up to get maximum participation.
- Step 6. Write draft report.
- Step 7. Produce final report.

Accomplishments

- Literature search was completed. Lists were created by sector and region; survey instruments were developed for each sector and method of contact.
- Site visits were conducted in Germany, the UK, Italy, South Korea, Japan, eastern and western Canada, and China.
- Survey instruments were revised on the basis of site visits. The number of open-ended questions was reduced to make responding by phone or mail easier and less time consuming. A document summarizing current U.S. government activities on fuel cells was created to provide phone and mail respondents with something in return for their participation.
- Phone interviews were conducted and mail surveys distributed and collected, with follow-up calls to assure maximum possible participation.
- Responses from site visits were analyzed.
- Report was produced and circulated.

Time Table

November 2000	DOE issues RFP for
September 2001	Cooperative Agreement signed with BTI
March 2002	Statement of work revised
July 2002	Site visits begin
September 2003	Data collection concludes
September 2003	Statement of work revised to reflect results of questionnaires
December 2003	Report submitted to DOE for approval

Significant contributions to the text were made by Kathryn Schein, Jennifer Gangi, and William Vincent.

Discussion

The Breakthrough Technologies Institute, Inc., entered a cooperative agreement with the U.S. Department of Energy in 2002 to facilitate site visits and conduct a survey of fuel cell vehicle developers, selected energy and component suppliers, and interested government agencies. Our purposes were to:

- Research, assess, and evaluate the current status, strategies, policies, and future plans of governments, major energy companies, major motor vehicle manufacturers, and developers of key components of fuel cells designed for use in motor vehicles in countries outside the United States.
- Attempt to measure the technical progress of companies in international markets against DOE's targets and goals.
- Assess the commercialization plans of companies and government programs to support commercialization.

The goals of the Fuel Cell Vehicle World Survey were revised twice to reflect the results of project outreach activities and the fast-changing fuel cell vehicle landscape. Originally, the goals were quite technical, but as the project progressed, the focus became more strategic.

The result is this snapshot of fuel cell motor vehicle development and major vehicle demonstrations around the globe. We hope it is useful for U.S. policy makers tracking the worldwide race to commercialize fuel cells and for U.S. companies interested in participating in the coming hydrogen economy.

This is an extremely fast-paced arena. New vehicles are being unveiled and component announcements made at an extraordinary rate. We have made every effort to provide timely and up-to-date information. We welcome corrections, additions, and comments.

The project attempted to gather as much information as possible directly from automobile manufacturers, fuel cell component companies, major energy companies, and governments. There are hundreds, if not thousands, of companies throughout the world working on some aspect of vehicular fuel cell development. The number of governments making significant investments in the development of fuel cells is increasing. To help us reach as many companies as possible, BTI contracted with several consultants, each knowledgeable in a particular region of the world. Extensive additional research was required to assure that BTI adequately surveyed the field.

Three survey methods were chosen: site visits, phone interviews and mailed questionnaires. Generally, BTI selected companies that were large enough, well-financed enough, or innovative enough to likely play a significant role in the development and/or eventual commercialization of fuel cell automobiles or buses.

One of the early challenges to the study's success involved motivating potential respondents to participate. BTI, in consultation with DOE, decided that priority participants would appreciate a briefing by DOE officials in conjunction with a site visit. The event would be viewed as an exchange of useful information by all those participating. Site visits were designed to be led by a consultant accompanied by DOE officials.

To encourage the participation of phone and mail respondents, a briefing paper outlining the current U.S. government approach to and initiatives supporting fuel cells for vehicular use was prepared for distribution.

We conducted a total of 53 site visits involving consultants and DOE representatives. Site visits were considered useful to both BTI and DOE personnel and the respondents. Meetings were held in Italy; Germany; the UK; China; Japan; South Korea; and Ottawa and Vancouver, Canada, and averaged two to three hours in length.

We distributed more than 150 questionnaires and made hundreds of telephone calls and additional site visits. Companies responding range widely in capitalization levels and workforce sizes.

Although some companies refused to participate in the study, many respondents were willing to discuss their business activities and their views on fuel cell development and the eventual commercialization of fuel cell vehicles as long as they were assured that their responses were not attributable. There was a greater reluctance to share technical data. We found similar attitudes in our telephone surveys and follow-up consultant visits. Overall, participants were extremely reluctant to share performance data and business projections.

Appendix B: Organizations Visited

Canada

Ballard
Fuel Cells Canada
Hydrogenics Corporation
Membrane Reactor Technology
Methanex
National Research Council
Natural Resources Canada
Questair
SMC Pneumatics
Stuart Energy
Xantrex

Europe

BadenWuerttemburg FC Initiative
BP
Ceres Power
DaimlerChrysler & Evo Bus
Forschungszentrum Julich
FuMa Technology
German Ministry of Economics and Technology
Greater London Authority
Intelligent Energy
Johnson Matthey
Linde
Lombardy regional government
MAN Nutzfahrzeuge
North Rhine Westfalia Fuel Cell Initiative
Nuvera/DeNora
OMG
Schunk Kohlenstofftechnik
SGL Carbon Group
Shell
Stuttgart Regional Economic Development Corporation (WRS)
UK Department of Trade and Industry
UK Department for Transport, Local Government and Regions

Japan

Fuel Cell Commercialization Conference of Japan (FCCJ)/Advancement Association of Japan (ENAA)
Fuel Cell Development Information Center (FCDIC)
Honda R & D Co., Ltd.
Honda Energy Systems Society (HESS)
Hydrogen Energy Systems Society and Engineering
Iwatani Corporation
Japanese Electric Vehicle Association
METI
Osaka Gas
Shell Hydrogen
Shikoku Research Institute

South Korea

Hyundai Motor Company
Korea Electric Power Corporation (KEPCO)
Korea Institute of Energy Research
Korea Institute of Science and Technology
LG Chemical
SK Corporation

Appendix C: Organizations Surveyed via Telephone, E-mail, and/or Mail

Telephone Interviews

Canada

BC Hydro
Cellex Power Products, Inc.
Chrysalix Energy Ltd.
Dynetek
Fuel Maker Corp.
General Hydrogen Corporation
GFI Control Systems, Inc.
Global Thermoelectric
Hera Hydrogen Storage Systems, Inc.
Pathway Design and Manufacturing

Europe

Air Liquide
BMW
"Club PAC"
European Union (special circumstances)
French government: Reseau PACo
Hydrogen Systems/Vandenboore Technologies
Irisbus
Ludwig-Bolkow-Systemtechnik GbmH
Morgan Fuel Cells
Norsk Hydro
Peugeot/Renault
Stat Oil
Sud Chemie
TOTAL/Fina-Elf
Vitrex plc.
Volvo
VW

Japan

Fuji Heavy Industries
Hino Bus — declined
Isuzu Advanced Engineering Center
Japan Steel Works

Japan Metals and Chemicals
Marubeni — spoke with U.S. rep.
Mazda — declined
Mitsubishi Heavy Metal Industries, Ltd. — declined
Mitsubishi Motors – e-mailed; no response
New Energy and Industrial Technology Development Organization — no response
Nippon Mitsubishi Oil — no English
Nissan Motors
Tokyo Gas
Toshiba International Fuel Cells Corporation — declined
Toyota Motor Corporation

E-Mailed Questionnaires

Canada

Canadian Hydrogen Association
Coast Mountain Bus Company — declined
Crystal Graphite Corporation
Energy Visions, Inc.
Greenlight Power Technologies, Inc.
Hydrogen Systems, Inc.
Hydro Quebec Research Institute
Palcan Fuel Cells Limited
Pivotal Power, Inc.
Technologies M4, Inc.
Westaim Ambeon

Europe

BASF
DaimlerChrysler (special circumstances)
Danish Energy Agency
Haldor Topsoe
Helion
Italian Ministry for the Environment
Nedstack BV
Netherlands Agency for Energy and Environment
Proton Motors
P21
Paul Scherrer Institute

Japan

Asahi Glass Co. Ltd.
Asahi Chemical Industry Company
Equos Research Co., Ltd.
Ishikawajima-Harma Heavy Industries
Japan Automobile Research Institute
Kogakuin University-KUCEL
Kosan Company
Mihama Corporation
Suzuki
Three Bond Co., Ltd.
Toho Gas
Tonen
Toray Industries, Inc.
Yamaha Motor Company, Ltd.

South Korea

HankookBEP Co. Ltd.
Korea Automotive Technology Institute
Seoul National University

Both Telephone and E-Mailed Questionnaires

China

Beijing Fuyuan Century Fuel Cell Power, Inc.
Beijing LNpower Company
China Association for Hydrogen Energy
China FAW Group Corporation (Changchun Yiqi)
Dalian Institute of Chemical Physics, Chinese Academy of Sciences
Economic Commission, Shanghai Municipal Government
General Research Institute for Nonferrous Metals
God Power Fuel Cell Corp.
Shanghai Automobile Industry Corp.
Shanghai Chemical Engineering Academy
Shanghai GM Automobile Corporation
Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences
Shanghai Jiaotong University
Shanghai Metallurgical Research Institute
Suzhou Machinery Holding (Group) Co., Ltd.
The Center of Automotive Engineering, Tongji University
The Ministry of Science and Technology (MOST)
The Science and Technology Commission, Beijing Municipal Government
The Science and Technology Commission, Shanghai Municipal Government
Tsinghua University

Taiwan

Asia Pacific Fuel Cell Technology Corporation
China Association for Intelligent Transportation Systems
Chinese Petroleum Corp
Department of Engineering and Applied Science, National Science Council
Energy Commission, The Ministry of Economic Affairs
Environmental Protection Agency
EVT Electrical Scooter Corp.
Industrial Technology Research Institute
Jemmytex International Corporation
Research Institute for Energy and Resources
R.O.C. Transportation Association
San Fu Chemical
Taipei Fuel Cell Foundation
Taiwan Fuel Cell Partnership
Taiwan Intelligent Transport System Association
Taiwan Transportation Vehicle Manufacturers Association

Glossary

ACTIVATION. Chemical. Treatment of a substance by heat, radiation, or other activating reagent to produce a more complete or rapid chemical or physical change. Electrical. The process of treating a cathode to increase its rate of reduction.

AIR. The mixture of oxygen, nitrogen, and other gases that, with varying amounts of water vapor, forms the atmosphere of the earth. Also referring to any or all air for combustion, heating, cooling, ventilation, and other uses as follows:

Ambient — Air that surrounds the equipment; Atmospheric — Air under the prevailing atmospheric conditions.

Recirculated — Air removed from a space and intended for reuse as supply air; Supply — That air delivered to each or any space in the system or the total delivered to all spaces in the system.

ALKALINE FUEL CELL (AFC). A type of hydrogen/oxygen fuel cell in which the electrolyte is concentrated KOH (35–50%, a liquid) and hydroxide ions (OH-) are transported from the cathode to the anode. Temperature of operation is typically in the range of 60–90ºC.

ANODE. The electrode in a fuel cell where electrons are produced.

AUXILIARY POWER. Power from an independent source that functions as required to augment/support various performance criteria established for the prime power source.

BALANCE-OF-PLANT. Supporting/auxiliary components, based on site-specific requirements and integrated into a comprehensive power system package centered around the power source.

BIPOLAR PLATES. Conductive plate in a fuel cell stack that acts as an anode for one cell and a cathode for the adjacent cell. The plate may be made of metal or a conductive polymer (which may be a carbon-filled composite). The plate usually incorporates flow channels for the fluid feeds and may also contain conduits for heat transfer.

BLOWER. A fan used to force air and/or gas under pressure.

BRITISH THERMAL UNIT. The mean British Thermal Unit (BTU) is 1/180 of the heat required to raise the temperature of one pound (1 lb) of water from 32ºF to 212ºF at a constant atmospheric pressure. It is about equal to the quantity of heat required to raise one pound (1 lb) of water 1ºF.

BURNER. A device for the final conveyance of the gas, or a mixture of gas and air, to the combustion zone (also see Main Burner).

CATALYST. A chemical substance that increases the rate of a reaction without being Consumed; after the reaction, it can potentially be recovered from the reaction mixture chemically unchanged. The catalyst lowers the activation energy required, allowing the reaction to proceed more quickly or at a lower temperature.

CATALYST-COATED MEMBRANE (CCM). Term used to describe a membrane (in a PEM fuel cell), the surfaces of which are coated with a catalyst/carbon/binder layer. (See also Membrane Electrode Assembly [MEA].)

CATALYST LOADING. The amount of catalyst incorporated in the fuel cell per unit area. Typical units for PEMFC are mg/cm^2.

CATHODE. The electrode in a fuel cell where electrons are consumed.

COMBUSTION. The rapid oxidation of fuel gases accompanied by flame and the production of heat or heat and light.

COMPRESSOR. A device used for increasing the pressure and density of gas.

CONDENSATE (CONDENSATION). The liquid that separates from a gas (including flue gases) as a result of a reduction in temperature.

CONTROLS. Devices designed to regulate the gas, air, water, or electrical supplies to the controlled equipment. These may be manual, semi-automatic, or automatic.

CONVECTION. Stirring or hydrodynamic transport. Generally, fluid flow occurs because of natural convection (convection caused by density gradients) and forced convection and may be characterized by stagnant regions, laminar flow, and turbulent flow.

CURRENT DENSITY. A vector-point function describing the magnitude and direction of charge flow per unit area, generally expressed in amperes per square meter.

DESULFURIZER. A component for removing sulfur from a fuel mixture.

DIFFUSION. Movement of a species under the influence of a gradient of chemical potential (i.e., a concentration gradient).

DIRECT INTERNAL REFORMING. Production of a desired product (hydrogen) within a fuel cell from a hydrocarbon based fuel (methanol, gasoline, etc.) fed to the fuel cell or stack.

DIRECT METHANOL FUEL CELL (DMFC). A type of fuel cell in which the fuel is methanol (CH_3OH), in gaseous or liquid form. The methanol is oxidized directly at the anode with no reformation to hydrogen. The electrolyte is typically a PEM.

DISTILLATE. A product formed by heating a liquid in a vessel and collecting and condensing the resulting by-product(s).

EFFICIENCY. A measure (usually a ratio) of the useful energy provided by a dynamic system versus the total energy supplied to it during a specific period of operation.

ELECTRICAL EFFICIENCY. The ratio of useful electrical real power output to the total electrical power input.

ELECTRODE. An electric conductor through which an electric current enters or leaves a medium, whether it be an electrolytic solution, solid, molten mass, gas, or vacuum.

ELECTRODE ASSEMBLY. The portion of an automatic ignition system containing the electrode(s) and associated insulators, wire lead terminals, spark gap adjustment means, and mounting brackets.

ELECTROLYTE. A nonmetallic insulating material in which current flow in an external circuit is made possible by the movement of ions through the electrolyte.

EXHAUST HEAT. Waste heat produced by a mechanical, chemical, or electrochemical process.

EXHAUST HEAT RECOVERY. The use of by-product heat as a source of energy.

EXTERNAL REFORMING. The production of hydrogen from a hydrocarbon fuel (methanol, gasoline, etc.) prior to entry to the fuel cell or stack.

FAN. A device consisting of a rotor and housing for moving air or gas at relatively low pressure differentials.

FLUE GASES. Products of combustion plus excess air in appliance flues or heat exchangers.

FLUE LOSSES. The sensible heat and latent heat above ambient temperature of the flue gases leaving gas utilization equipment.

FUEL CELL. An electrochemical device that can continuously convert the chemical energy of a fuel and an oxidant to electrical energy. The fuel and oxidant are typically stored outside of the cell and transferred into the cell as the reactants are consumed.

GAS. Fuel gas, such as natural gas, undiluted liquefied petroleum gases (vapor phase only), liquefied petroleum gas-air mixtures, or mixtures of these gases.

GAS TURBINE. A turbine rotated by expanding gases.

GROSS POWER. The fundamental power output of an energy source prior to any conditioning and losses associated with the production of power suitable for the connected load.

HEAT EXCHANGER. A vessel in which heat is transferred from one medium to another.

HYDROCARBON. A chemical compound of hydrogen and carbon, such as methane, propane, butane, etc.

IMPURITIES. Undesirable foreign material(s) in a pure substance or mixture.

INDIRECT INTERNAL REFORMING. The reformer section is separated, but adjacent to, the fuel cell anode. This cell takes advantage of the close coupled thermal benefit where the exothermic heat of the cell reaction can be used for endothermic reforming reaction.

INTERCOOLER. A heat exchanger for cooling gas between stages of a multistage compressor with a consequent saving in power.

IR LOSS. In an electrolytic cell, the loss equal to the product of the current (I) passing through the cell and the resistance (R) of the cell. Also referred to as IR drop.

I2R LOSS. Power loss due to the current (I) flow through the resistance (R) of a conductor.

LOAD-FOLLOWING. A mode of operation where the fuel cell power plant is generating variable power depending on the AC load demand.

LOW EMISSION VEHICLE (LEV). LEV, Low Emission Vehicle, referring to those light-duty passenger vehicles that meet LEV emission control standards. California's Air Resources Board and the federal EPA set standards for tailpipe emissions and air emissions related to the volatility of fuel used in passenger cars and light trucks. California has established several categories of vehicles, on the basis of the maximum permitted emissions of several pollutants. (See chart below.) In addition, California has a credit program called PZEV (Partial ZEV) designed to stimulate sales of vehicles with Zero Emission Vehicle characteristics. California has also established a fleet-wide emission control requirement.

California LEV II Light-Duty Vehicle Standards			
	Vehicle Emission Category (grams/mile)		
	NMOG	Carbon Monoxide	Oxides of Nitrogen
TLEV	0.156	4.200	0.600
LEV	0.090	4.200	0.070
ULEV	0.055	2.100	0.070
SULEV	0.019	1.000	0.020

MAIN BURNER. A device or group of devices essentially forming an integral unit for the final conveyance of gas or a mixture of gas and air to the combustion zone and on which combustion takes place to accomplish the function for which the equipment is designed.

MANIFOLD. The conduit of an appliance that supplies gas to the individual burner.

MEANTIME BETWEEN FAILURES. The mean exposure time between consecutive failures of a component. It can be estimated by dividing exposure time by the number of failures in that period, provided that sufficient number of failures has occurred in that period.

MEAN TIME TO REPAIR. The time interval (hours) that may be expected to return a failed equipment to proper operation.

MEMBRANE. The separating layer in a fuel cell that acts as electrolyte (a cation-exchanger), as well as a barrier film separating the gases in the anode and cathode compartments of the fuel cell.

MEMBRANE ELECTRODE ASSEMBLY (MEA). Structure consisting of a proton-exchange membrane with surfaces coated with catalyst/carbon/binder layers and sandwiched by two microporous conductive layers (which function as the gas diffusion layers and current collectors).

MOLTEN CARBONATE FUEL CELL (MCFC). A type of fuel cell consisting of a molten electrolyte of Li_2CO_3/Na_2CO_3 in which the species CO_3 2- is transported from the cathode to the anode. Operating temperatures are typically near 650ºC.

NAPHTHA. An artificially produced petroleum or coal tar fraction with a volatility between gasoline and kerosene.

NATURAL GAS. A naturally occurring gaseous mixture of simple hydrocarbon components (primarily methane) used as a fuel for the production of electrical power.

NERNST POTENTIAL. An electrode potential corresponding to the reversible equilibrium between hydrogen gas at a certain pressure and the corresponding level of hydrogen ion activity.

OXYGEN-TO-CARBON RATIO. The ratio of the number of oxygen atoms to the number of carbon atoms in the fuel (e.g., methanol would have a ratio of 1, ethanol would have 0.5).

PARTIAL OXIDATION. Fuel reforming reaction in which the fuel is partially oxidized to carbon monoxide and hydrogen rather than fully oxidized to carbon dioxide and water. This is accomplished by injecting air with the fuel stream prior to the reformer. The advantage of partial oxidation over steam reforming of the fuel is that it is an exothermic reaction rather than an endothermic reaction and therefore generates its own heat.

PHOSPHORIC ACID FUEL CELL (PAFC). A type of fuel cell in which the electrolyte consists of concentrated phosphoric acid (H_3PO_4), and protons (H+) are transported from the anode to the cathode. The operating temperature range is generally 160–220ºC.

POLARIZATION CURVE. Typically a plot of fuel cell voltage as a function of current density (V vs. A/cm^2 or similar units). The curve is obtained under standard conditions so that fuel cell performance can be compared between different cell designs and may be obtained by either a single cell or a stack test.

POWER CONDITIONING. The subsystem that converts the dc power from the (fuel cell) stack subsystem to ac power that is compatible with system requirements.

POWER DENSITY. (kW/liter) In the context of a single cell, the power density is often measured in terms of power/unit area of active cell (e.g., kW/m^2); in the context of a complete cell stack, the power density could also be defined in terms of power/unit stack volume (e.g., kW/m^3).

PREFERENTIAL OXIDATION. A reaction that oxidizes one chemical rather than another. In fuel cells, the reaction is used to preferentially oxidize carbon monoxide from the reformate stream after the water-gas shift reactor and before the fuel cell. Same as selective oxidation.

PRESSURE. The force exerted against an opposing body or the thrust distributed over a surface, expressed in weight per unit of area. Absolute — The pressure above zero pressure, the sum of the atmospheric and gauge pressures. Atmospheric (Standard) — The pressure of the weight of air and water vapor on the surface of the earth at sea level, namely 29.92 inches (760 mm) mercury column or 14.69 pounds per square inch (101.3 kPa). Barometric — The atmospheric pressure as determined by a barometer, usually expressed in inches (mm) of mercury. Gauge — The pressure above atmospheric pressure. Vacuum — Any pressure less than that exerted by the atmosphere.

PROTON EXCHANGE MEMBRANE (PEM). The separating layer in a PEM fuel cell that acts as an electrolyte (which is proton conducting), as well as a barrier film separating the hydrogen-rich feed in the cathode compartment of the cell from the oxygen-rich anode side.

PROTON EXCHANGE MEMBRANE FUEL CELL (PEMFC or PEFC). A type of fuel cell in which the exchange of protons (H+) from the anode to the cathode via a membrane is involved in the chemical reaction producing electricity. The electrolyte is a called proton exchange membrane (PEM). The fuel cells typically run at low temperatures (<100ºC) and pressures (< 5 atm).

REACTION RATE. A measure of the speed of a chemical reaction. The reaction rate depends on the rate constant, the number of reactants involved in the reaction, and their concentration. For reactions that are otherwise slow, a catalyst is employed to increase the reaction rate.

REFORMER. A vessel within which fuel gas and other gaseous recycle stream(s) (if present) are reacted with water vapor and heat, usually in the presence of a catalyst, to produce hydrogen-rich gas for use within the fuel cell power plant.

REFORMATE GAS. The fluid that exits the fuel reformer and acts as feed to the fuel cell stack.

REFORMING. The thermal or catalytic conversion of petroleum naphtha into more volatile products with higher BTU ratings.

REVERSIBLE FUEL CELL. A type of fuel cell in which the chemical reactants undergo reversible reactions, such that the cell may be recharged with a separate power source if desired. For example, the hydrogen/oxygen fuel cell may be recharged by providing power for water electrolysis with hydrogen storage. Also called Regenerative Fuel Cell.

SERIES CONNECTION. The connection of electrical cells in a positive to negative pattern such that individual cell voltages are additive.

SHIFT CONVERSION. The reaction of CO and water to hydrogen and carbon dioxide. This process is performed immediately after the reformer and before the preferential oxidizer and reduces CO from approximately 10% down to 0.5% to 0.1% usually through a water-gas shift reaction.

SOLID OXIDE FUEL CELL (SOFC). A type of fuel cell in which the electrolyte is a solid, nonporous metal oxide, typically ZrO_2 doped with $Y2O_3$, and O_2- is transported from the cathode to the anode. Any carbon monoxide (CO) in the reformate gas is oxidized to carbon dioxide (CO_2) at the anode. Temperatures of operation are typically 800–1000ºC.

STACK LIFE. The cumulative period that a fuel cell stack may operate before its output deteriorates below a useful minimum value.

STACK TEST. Experiment where an electrical load is applied to a stack of fuel cells to determine its ability to perform. Normally, the output seeks two pieces of information: First is a current output at a specific cell voltage point; second is a continuous voltage vs. current curve (polarization curve).

STACKING. The process of placing individual fuel cells adjacent to one another to form a fuel cell stack. Normally, the stack is connected in a series.

STEAM REFORMING. A process for separating hydrogen from a hydrocarbon fuel, typically natural gas, in the presence of steam. This is the commonly preferred method of bulk hydrogen generation.

STEAM-TO-CARBON RATIO. The number of moles of water per mole of carbon in either the reformate or the fuel streams. This term is used when steam is injected into the reformate stream for the water-gas shift reaction or into the fuel for steam reforming.

SUBSTACK. Typically a group of stacked fuel cells that makes up the base repetitive unit number of cells per full system stack. Substacks may form an intermediate step in manufacturing and may be used to test new stack concepts prior to scale up to full-size stacks.

TEMPERATURE. A measure of heat intensity. Absolute — The temperature above absolute zero, or temperature plus 273ºC or 459ºF. Ambient — The temperature of the surrounding medium, usually used to refer to the temperature of the air in which a structure is situated or a device operates.

THERMAL EFFICIENCY. Efficiency with which a power source transforms the potential heat of its fuel into work or output, expressed as the ratio of the useful work done by the power source in a given time interval to the total heat energy contained in the fuel burned during the same time interval, both work and heat being expressed in the same units.

THERMAL MANAGEMENT. The directing of heat entering or exiting a system.

TRANSPORTATION. Term applied to the market section that includes light-duty vehicles, buses, heavy-duty vehicles, and off-road vehicles.

TUBULAR CELLS. Fuel cells that are formed in cylindrical fashion and allow fuel and oxidant to flow on the inner or outer surfaces of the pipe.

TURBOCHARGER. A device used for increasing the pressure and density of a fluid entering a fuel cell power plant using a compressor driven by a turbine that extracts energy from the exhaust gas.

TURBOCOMPRESSOR. Machine for compressing air or other fluid (reactant if supplied to a fuel cell system) in order to increase the reactant pressure and concentration.

TURBOEXPANDER. Machine for expanding air or other fluid (reactant if supplied to a fuel cell system) in order to decrease the reactant pressure and concentration. The unit is normally used in conjunction with a compressor to recover unused energy from hot, pressurized gases, thereby reducing the net amount of energy required to power the compressor.

VESSEL, PRESSURE. Containers for the containment of pressure either internal or external. This pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or by any combination thereof. Exceptions: vessels having an internal or external operating pressure not exceeding 15 psi (103.4 kPa) with no limitation on size; vessels having an inside diameter, width, height, or cross section diagonal not exceeding six (6) inches (152 mm) with no limitation on length of vessel or pressure.

ZERO EMISSION VEHICLE (ZEV). A vehicle that produces no air emissions from its fueling or operation. California regulations require that in 2003, 10% of the vehicles sold in California by major automakers be ZEV or ZEV-equivalent. California has established a comprehensive program for determining this equivalency. See also LEV.

Conversion Tables

For accuracy, investment and sales figures generally are expressed in local currency. Exchange rates of some major currencies are listed below.

U.S. Dollar Equivalents			
Currency	*Symbol*	*1/1/2003*	*12/1/2003*
One thousand Euro	€	$1,042	$1,196
1 million Yen	¥	$8,420	$9,120
One thousand Canadian Dollars	CAN$	$633	$768
One thousand Australian Dollars	AUS$	$562	$726

Units of Measure
One kilometer (km) = 0.62 miles
One mile (mi) = 1.61 kilometers
One kilogram (kg) = 2.2 pounds
One pound (lb) – 0.45 kilograms
One liter (L) = 0.26 gallons
One gallon (gal) = 3.78 liters

U.S. Fuel Cell Council
1625 K Street, N.W., Suite 725
Washington, D.C. 20006
Phone: (202) 293-5500
Fax: (202) 785-4313
www.usfcc.com

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

For more information contact:
EERE Information Center
1-8779EERE-INF (1-877-337-3463)
www.eere.energy.gov