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.

Partnerships:

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.

<u>Partnerships:</u>

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)

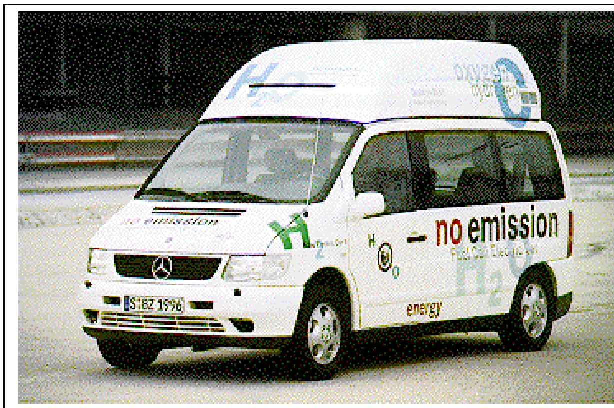
FUEL TYPE	Methanol
ENGINE TYPE	Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE	50 kW/PEM
FUEL CELL MANUFACTURER	Ballard Mark 700 series
RANGE	118 mi (190 km)
MPG EQUIVALENT	24 mpg
MAX SPEED	n/a

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)

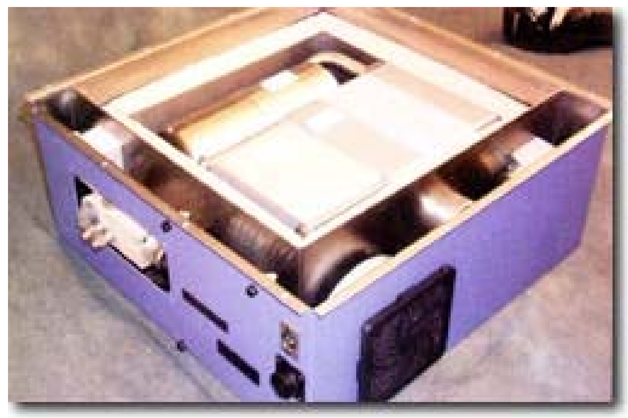
FUEL TYPE	
Compress. H_2 @ 4,300 psi	
ENGINE TYPE	
12 fuel cell stacks	
FUEL CELL SIZE/TYPE	
50 kW/PEM	
FUEL CELL MANUFACTURER	
Ballard	
RANGE – 81 mi (130 km)	
MPG EQUIVALENT – n/a	
MAX SPEED – 56 mph (90 km/h)	

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.

<u>Partnerships:</u>
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.)

Partnerships:

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.

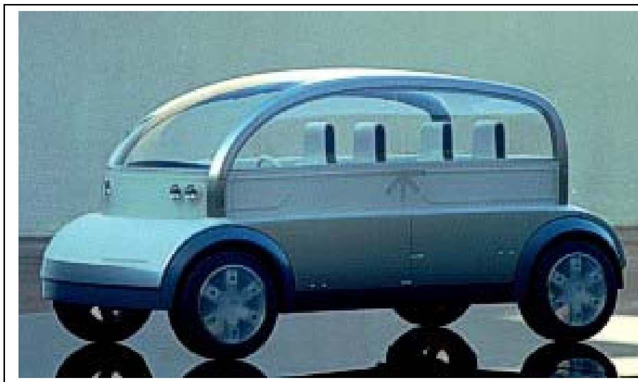
Hydrogen Combustion

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.

<u>Partnerships:</u>

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

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

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)

2002
Advanced HydroGen 3 (Zafira van)

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
Hy-Wire (proof of concept)

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
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)

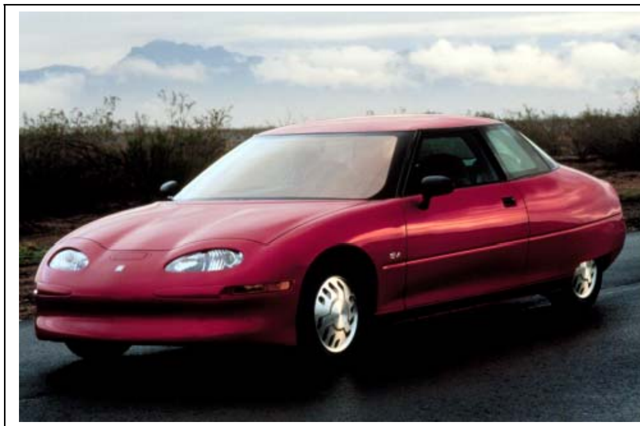
FUEL TYPE
Hydrogen (stored in metal hydride)
ENGINE TYPE
Fuel cell/battery hybrid
FUEL CELL SIZE/TYPE
100 kW/PEM
FUEL CELL MANUFACTURER
GM/Hydrogenics
RANGE – 500 mi (800 km) est.
MPG EQUIVALENT – 108 mpg est.
MAX SPEED – 120 mph (193 km/h)

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

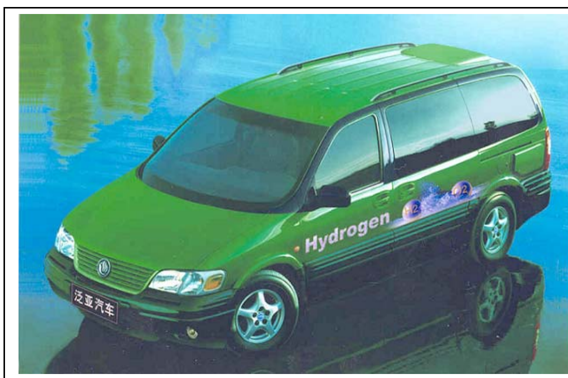
The zero-emission fuel cell wagon, called the **Phoenix**, is based on a Buick GL8 from Shanghai GM, GM's vehicle assembly joint venture in China. It was unveiled November 2002 in Shanghai. PATAC took the lead on the project, integrating the fuel cell system into the vehicle. Scientists and engineers 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

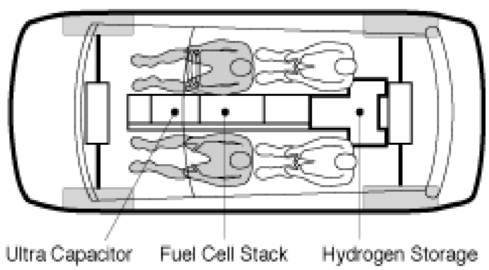
Honda claims its **FCX** is the first fuel cell car to be certified by the California Air Resources Board (CARB) and the Environmental Protection Agency (EPA) for everyday use. The FCX has been certified by CARB as a Zero Emission Vehicle (ZEV) and by EPA as a Tier-2 Bin 1, National Low Emission Vehicle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

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 – 220 mi (355 km)
MPG EQUIVALENT – ~50 mpg
MAX SPEED – 93 mph (150 km/h)

2001
FCX-V4

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)

2000
FCX-V3

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)

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.

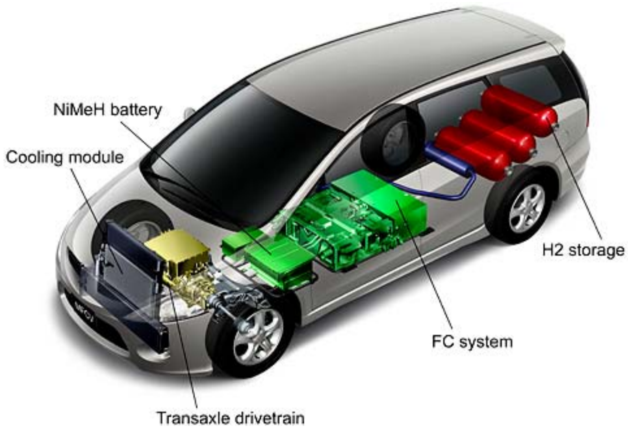
The company in recent years produced a full line of vehicles, from minicars to passenger autos, trucks, and buses. In 2002, Mitsubishi Motors sold 1.6 million passenger cars and had net sales of ¥3,885 billion. Mitsubishi employs more than 45,000 people.

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.

<u>Partnerships:</u>
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.

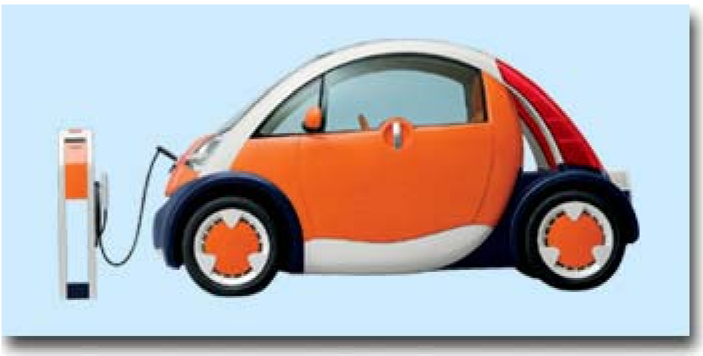
Suzuki is now part of the GM development team. Suzuki expects to concentrate on those development areas it knows best, such as miniaturization.

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.

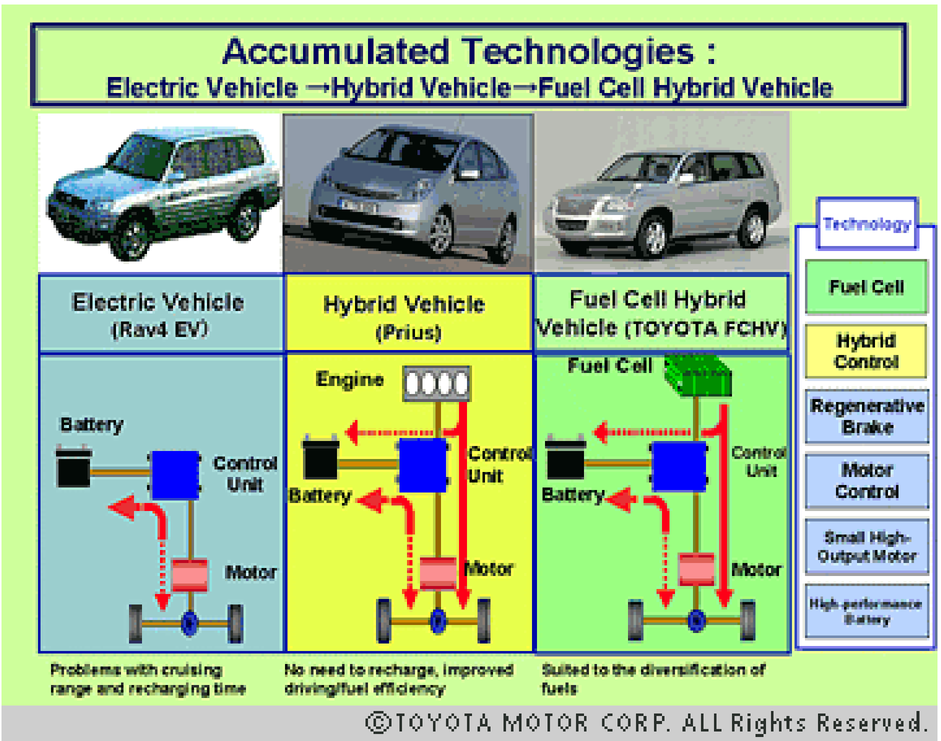
<u>Partnerships:</u>
1. GM (1999), fuel cell technology
2. Daihatsu (1999), fuel cell research and development
3. ExxonMobil (2001), fuel cell research
4. Hino Motors (2002), fuel cell bus
5. Giner Inc.

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.

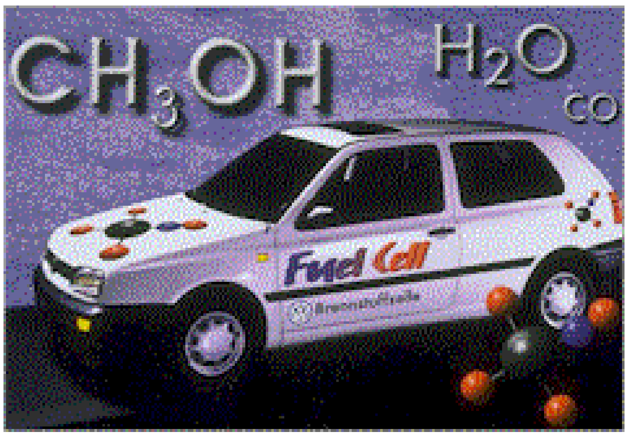
Gallery

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