Fuel Cells in Transit Buses

Summary

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

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

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

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

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

The roof mounting also appears to offer advantages. The small size of the hydrogen atom makes storage systems more likely to leak than storage systems for other fuels. The roof mounting enables the hydrogen to quickly dissipate into the atmosphere, if a leak should occur. Moreover,

the roof of the bus is very unlikely to be damaged in the event of a traffic collision, thus helping to ensure the integrity of the tanks.

Demonstrations

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

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

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

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

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

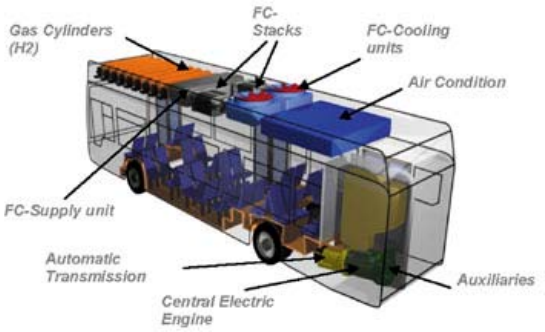
DaimlerChrysler

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

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

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

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



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

Company Information

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

Irisbus

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

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

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

Company Information

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

Gillig

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

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

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

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

Company Information

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

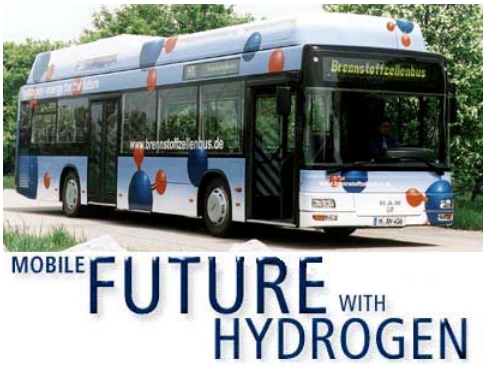
MAN

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

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

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

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



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

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

Company Information

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

NABI (North American Bus Industries)

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

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

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

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

Company Information

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

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

Neoplan

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

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

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

Company Information

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

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

New Flyer Industries

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

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

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

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

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

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

Company Information

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

Nova Bus

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

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

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

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

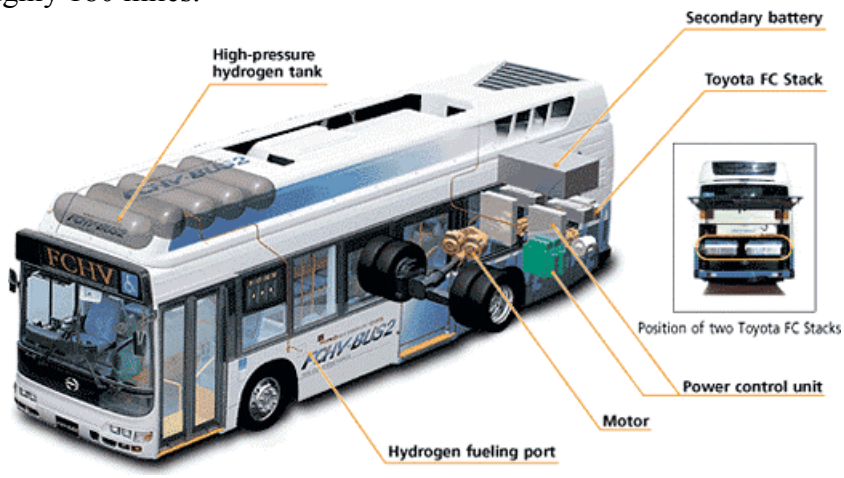
Company Information

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

Toyota

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

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



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

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

Company Information

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

Thor Industries, Inc.

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

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

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

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

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

Company Information

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

Van Hool

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

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

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

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

Company Information

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

Volvo Bus

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

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

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

Company Information

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

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