

# Georgetown University Fuel Cell Transit Bus Program

## Maintaining the Liquid-fueled Option

**Samuel Romano**  
**James T. Larkins**  
**Georgetown University**

**Introduction:** Georgetown University (GU) has been at the forefront in the development of transportation Fuel Cells for over nineteen years. GU has been involved in the development, demonstration and testing of several Fuel Cell power plants and vehicles, including three 30-foot transit buses and two 40-foot transit buses. All of these vehicles are still operational. GU rolled out a 40-foot Fuel Cell powered transit bus May 1998. This electric bus is powered by a 100kW Phosphoric Acid Fuel Cell (PAFC) manufactured by UTC Fuel Cells, LLC. A second 100kW Proton Exchange Membrane Fuel Cell (PEMFC) power plant has been fabricated by Ballard Transportation Business Unit and has been integrated into a second 40-foot transit bus platform. This is the world's largest PEMFC power plant capable of operating on liquid fuel; it rolled out in December 2001.

The GU program is the only one of its kind that is addressing the commercialization of the easily refueled and longer-range, liquid-fueled Fuel Cell buses; methanol is the fuel of choice. As a hydrogen carrier, methanol greatly exceeds the on-board vehicular weight percent storage targets for hydrogen set by the US Department of Energy (DOE). Coal, an abundant US domestic fuel, can be used to produce methanol. The potential to make domestic coal the feedstock for transportation fuel cannot be ignored. This offers a realistic approach to true energy independence. The GU Fuel Cell Powered Transit Bus Program is supported by a grant from the Federal Transit Administration (FTA).

The broad objective of the FTA Fuel Cell Bus Program was levied in the US Senate Committee Report 102-351 (1993), at a time when very few industrial concerns were involved in Fuel Cell vehicle development, which decried that "...Funds are for front-end costs to make US manufacturers and suppliers ready for production of Fuel Cell propulsion buses..." Toward that objective, FTA and GU defined a program that would design, manufacture and test fully-integrated, heavy-duty transit buses. This approach was deemed the only path that could demonstrate system effectiveness while simultaneously exposing any technical deficiencies at the vehicle level. The subsequent increase in Fuel Cell vehicle development is an indication of the success of that mandate.

**GU Program Description:** GU has consistently maintained that the quickest path to widespread acceptance of the Fuel Cell powered transit bus dictates the use of liquid fuel. Transit agencies in the United States are comfortable and familiar with refueling vehicles with liquid fuels at atmospheric pressure. While gaseous hydrogen operation alleviates major concerns with near-term Fuel Cell development (primarily the development of a responsive fuel processor) and yields a more efficient Fuel Cell power plant, there is insufficient storage capability on a transit bus to achieve the range requirements (typically 350-400 miles) of most US transit operators due to the low volumetric density of high-pressure gaseous hydrogen storage. Additionally,

important fueling infrastructures are still outstanding for gaseous hydrogen fuel which could further limit commercial acceptance by the transit industry.

In 1994, GU rolled out the first of three Fuel Cell powered hybrid electric 30-foot buses; the following two were rolled out in 1995. These buses are methanol-fueled, proof-of-concept vehicles and use a 50 kW Phosphoric Acid Fuel Cell (PAFC) power plant as the main energy source. All three of these vehicles are still operating. Figure 1a shows the 30-foot TBB while Figure 1b is a photograph of the rear compartment showing the Fuel Cell installation.



**Figure 1a. 30-Foot Test Bed Bus (TBB)**



**Figure 1b. 50kW Fuel Cell in TBB**

To date, two fully functional 40-foot Fuel Cell transit buses have been fabricated and tested within this program. The buses seat 40 passengers, meet every performance requirement of the transit industry, are very quiet, have a design range of 350 miles between refueling, and have much lower emissions than standard diesel buses. In 1994, UTC Fuel Cells (then known as International Fuel Cells), a division of United Technologies Corporation, was contracted by GU to develop a 100 kW PAFC power plant for transit bus use. This first bus rolled out in 1998. Figures 2a and 2b show the 40-foot PAFC bus and Fuel Cell installation.



**Figure 2a. 40-foot PAFC Generation 1 Bus**

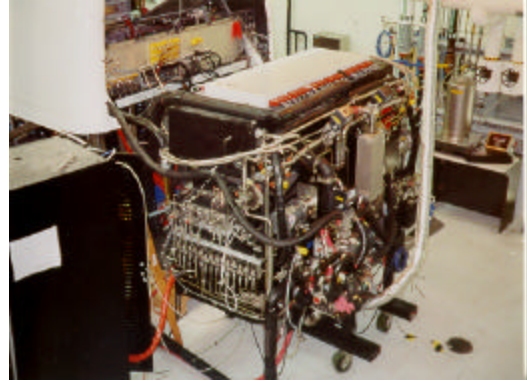


**Figure 2b. 100 kW PAFC in Bus**

GU introduced the first and only urban transit bus powered by a liquid-fueled 100 kW Proton Exchange Membrane Fuel Cell (PEMFC) developed by Ballard Power Systems at a meeting hosted by the California Air Resources Board in December 2001. This PEMFC is the world's largest capable of operating on liquid fuel. Figure 3a is the 40-foot PEMFC bus and Figure 3b depicts the 100 kW PEMFC power plant behind the rear section of the bus.



**Figure 3a. 40-foot PEMFC Generation 1 Bus**



**Figure 3b. 100 kW PEMFC Behind Bus**

**Fuel Selection:** Every US automobile manufacturer and most foreign firms have major programs underway to develop Fuel Cell engines for transportation. Most near-term developments are based upon using on-board stored hydrogen gas as the fuel source. This may be a prudent and cost-effective choice to facilitate development of the vehicles and to garner public acceptance and understanding of the technology. However, the key question that will dictate long-term commercial success is the choice of fuel for the Fuel Cell automobiles.

To date, the appropriate fuel for commercialization has not been selected due to the contentious nature of that decision, the strong convictions of proponents, and the evolving state of transportation Fuel Cell technology. This issue needs to be addressed in a thorough and honest manner. Regardless of personal preferences by the various advocates, the marketplace will determine the correct fuel.

There are three major issues affecting the commercialization of hydrogen Fuel Cell automobiles: the cost of the fuel, severity of requisite fueling infrastructure, and vehicle range which is limited due to on-board storage requirements. Essentially, success is totally dependent upon introducing a “hydrogen economy” within a generation. This is a steep challenge that transcends the capacity of the individual major stakeholders (energy companies, automobile manufacturers, or Fuel Cell suppliers). It is time to reconsider the methanol option.

As a hydrogen carrier, methanol is liquid at ambient temperature, has no sulfur or other Fuel Cell poisons, and should be able to fit existing infrastructure with minimum impact and cost. This fuel is readily available in quantities that support successful commercial introduction at a cost that is competitive with current automobile fuel. This liquid fuel has the necessary volumetric density to yield a range sufficient for consumer acceptance. There have been several Fuel Cell vehicles that have shown successful operation on methanol (see Figure 4). In 2002, a DaimlerChrysler NeCar 5 methanol vehicle (Figure 4b) crossed the United States from San Francisco to Washington, DC and demonstrated a range of over 300 miles between refueling.



**Figure 4a: NeCar 3  
2000**



1997

**Figure 4b: NeCar 5**



**Figure 4c: Jeep Commander 2      2000**



**Figure 4d: Mazda Premacy      2001**

**Evolution of the Current Automotive Fuel Strategy:** Throughout the 1990s, only two candidate Fuel Cell technologies were considered viable for transportation Fuel Cells: the PAFC and the PEMFC. At that time, the automotive community considered liquid-fuel operation mandatory for successful automobile introduction, and the PEMFC technology was the preferred choice due to a variety of technical reasons. The PAFC operates at a higher temperature (approximately 370<sup>0</sup> F) than the PEMFC (approximately 180<sup>0</sup> F). Due to its higher operating temperature, the PAFC can accept as much as 1-2% Carbon-Monoxide (CO) in the hydrogen-rich gas produced by the fuel processor. GM demonstrated the world's first liquid-fuel Fuel Cell vehicle using a PAFC with the introduction of the 30-foot Test Bed Bus in 1994.

The PEMFC is far less tolerant of CO in its fuel stream (limited to approximately 50 ppm or less). Thus, the key limiting factor for liquid-fueled PEMFC technology was the fuel clean-up process, primarily the removal of CO from the gas stream to the Fuel Cell stack. Until this technical challenge could be surmounted, PEMFC technology would not be considered for automotive applications. In 1997, DaimlerChrysler solved the PEMFC liquid-fuel challenge

using a Selective Oxidization (SelOx) process (often referred to as, “Preferential Oxidization”) to reduce CO in the fuel stream and demonstrated the effectiveness of that approach in the NeCar 3. The concept of a liquid-fueled PEMFC automobile rapidly galvanized the automobile community. Early adoption of the technology appeared feasible. When and if hydrogen fuel becomes practical with the adoption of the hydrogen economy, a transition to that fuel could be easily made and Fuel Cells would become even more attractive. However, this approach required an “interim” methanol fuel infrastructure. The cost and effort to build such an infrastructure was significant and possibly not warranted if the hydrogen economy was on the horizon. Energy companies teamed with the automobile industry and Fuel Cell vendors in an attempt to use gasoline as the near-term liquid fuel. Thus the potential stranded methanol infrastructure issue would disappear. Methanol rapidly lost favor as the preferred near-term solution.

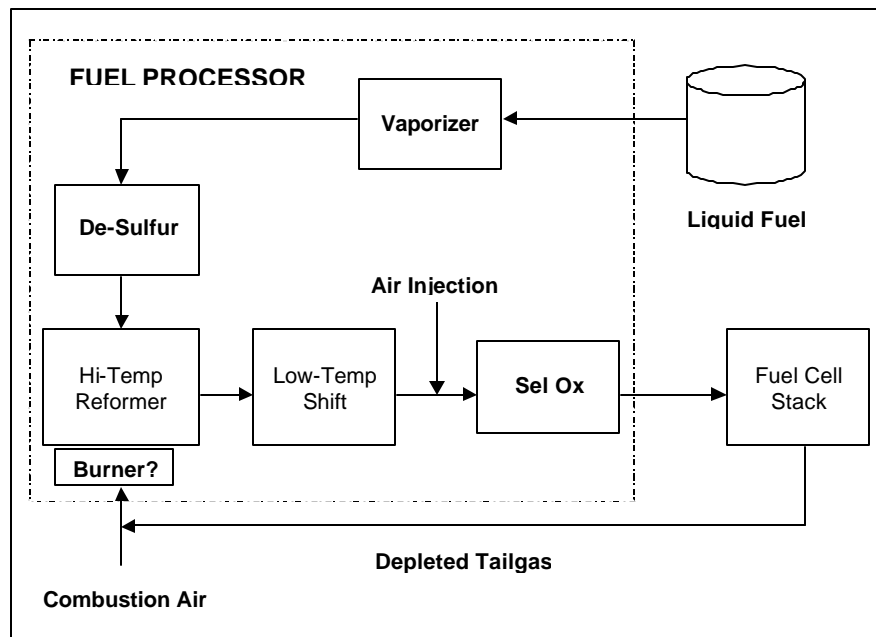
Unfortunately, gasoline proved a very difficult fuel for Fuel Cell application. While there have been successful gasoline fuel processing demonstrations, the test hardware has not been integrated into a responsive automobile Fuel Cell power plant. Fuel Cells cannot tolerate sulfur. Gasoline (even low-sulfur gasoline) has sulfur and other additives that must be removed. Additionally, the fuel must be vaporized and reformed at a relatively high temperature and shifted to a lower temperature before introduction to a final fuel cleanup stage. This introduces complexity, hardware, emissions and inefficiency, while limiting power plant responsiveness. Work continues to mitigate these concerns, but the preponderance of the Fuel Cell industry (Fuel Cell vendors, automotive suppliers and energy companies), along with the US Department of Energy (DOE) have moved away from a liquid fuel solution. We are now on the hydrogen path!

This change in direction has several significant impacts. The technology barriers to early demonstration of hydrogen Fuel Cell automobiles are not great. There have been a plethora of such demonstration vehicles to date. However, the date of commercial introduction of the technology has been pushed out. At the end of the last decade, claims of commercial vehicles being available by 2004/2005 were common. Now, commercial introduction is envisioned in ten or fifteen years (or more). In no small measure, this can be attributed to the significant hurdles of hydrogen as a transportation fuel and the introduction of the hydrogen economy. It is time to reconsider the methanol option.

**Fuel Processing:** Fuel Processing is defined (for this paper) as the subsystem of a Fuel Cell power plant that converts a raw fuel (other than pure hydrogen) into the hydrogen-rich gas needed to achieve the proper electrochemical reaction within a Fuel Cell stack. The raw fuel can be any carrier of hydrogen such as natural gas (methane), methanol, ethanol, gasoline, diesel fuel, or JP-8. The latter two are key logistic fuels for the US military. The necessary steps that must be achieved within the Fuel Processing operation are:

1. Vaporization (if the raw fuel is a liquid)
2. De-sulfurization (if sulfur greater than one part per million (1 ppm) is present in the raw fuel)
3. Reformation – breaking the raw fuel into hydrogen and other chemical constituents
4. Clean-up – achieving the proper purity of the hydrogen-rich gas

To date, methanol ( $\text{CH}_3\text{OH}$ ) is the only liquid fuel that has been successfully processed and demonstrated as a raw fuel for a practical transportation Fuel Cell power plant. This fuel can be 1) easily vaporized at a low temperature, 2) obtained with little or no sulfur, and 3) reformed with relatively straightforward techniques using low-temperature steam reforming ( $\sim 400^\circ\text{F}$ ). Thus, an efficient, responsive, and clean Fuel Cell power plant can be realized. It has been done. Figure 5 depicts the generic fuel processing stages.



**Figure 5. Typical Fuel Cell Power System Fuel Flow Diagram for Hydrocarbon Fuels**

**Energy Independence:** The driving arguments for the introduction of Fuel Cells for transportation have been efficiency and environmental benefits. It should be strongly emphasized that Fuel Cell vehicles can also provide a path towards true energy independence. An alternative to using natural gas for the methanol feedstock that could have long-term strategic importance is coal. Coal, an abundant domestic fuel, can be used to produce methanol. The DOE has co-funded the development of a Liquid Phase Methanol process to convert syngas made from coal to methanol. In 1997, a demonstration project at Kingsport, TN was placed in operation with the capacity to produce 80,000 gallons of methanol per day (nominal). This process offers the promise to manufacture methanol at a cost competitive with that produced from natural gas and make domestic coal the feedstock for this nation's transportation fuel. The potential to make domestic coal the feedstock for transportation fuel cannot be ignored. This offers a realistic approach to true energy independence.

**Maintaining the Liquid-fuel Option:** The Fuel Cell buses developed to date by GU require energy storage (traction battery) to achieve the desired transit bus performance. This hybrid configuration is too heavy and complex to meet the commercialization goals of the transit industry. Fuel Cell technology, spurred by automotive developments, has greatly improved since the development of these earlier generation buses. A commercial 40-foot Fuel Cell bus requires a PEMFC power plant with twice the power ( $>200\text{ kW}$ ) but with similar weight and volume

parameters to the current 100 kW Fuel Cells. These objectives can be achieved if new automotive Fuel Cells can be combined electrically. This approach greatly reduces the energy storage (battery) requirement thus yielding a transit bus compatible with the industry needs. To meet the commercialization objectives levied for this program, additional vehicles (minimum of three) should be fabricated and delivered into the hands of transit agencies in order to demonstrate the benefits of this vital technology and identify any needed technology improvements to achieve widespread commercialization. These vehicles will employ advanced PEMFC technology based upon upgraded automotive Fuel Cell technology. This step is absolutely essential to foster public awareness of this paradigm in transportation propulsion technology and to introduce Fuel Cell propulsion systems into commercial production.

**Summary:** While the development of Fuel Cell buses using highly pressurized gaseous hydrogen fuel is taking place, the GU program is the only one of its kind that is addressing the commercialization of the easily refueled and longer range liquid-fueled Fuel Cell buses. It is essential to maintain fuel options. Operational issues surrounding the selection of fuel have not been fully addressed, and a premature decision could undermine the potential for effective widespread commercialization of Fuel Cell technology. Transit operators do not want to limit fuel options until a more thorough evaluation of all alternatives can be completed. The nation should not accept less.