FUEL CELLS FOR TRANSPORTATION

Los Alamos National Laboratory, Los Alamos, NM 87545 (U.S.A.)

The purpose of this program is to conduct basic and applied research in electrochemistry to explore and improve the potential of fuel cell systems for use in transportation applications.

Advances have been made in the program in several areas. Activities have included assessments of several fuel cell technologies as related to the demands of transportation applications, preliminary efforts to adapt a methanol reformer for use on a fuel-cell-powered golf cart, and basic research on electrode kinetics and mechanisms, particularly those of the oxygen electrode in various electrolytes.

In 1981, Los Alamos National Laboratory (LANL) initiated three design studies with United Technologies Corporation (UTC), Energy Research Corporation (ERC), and General Electric Company (GE) to assess the potential of phosphoric acid (PAFC), trifluoromethanesulfonic acid (TFMSA), and solid polymer electrolyte (SPE) fuel cell technologies, respectively, as related to the demands of a small consumer automobile (based on a General Motors X car).

Because the requirements imposed on the fuel cell by vehicular applications and the system design trade-offs in both the fuel cell and vehicular systems are quite different from those of previous fuel cell applications, these studies provided the first opportunity for in-depth thinking about fuel cell designs specific to vehicular applications. Through the iterations of first-order designs based on present and projected technology with the system requirements derived from LANL computer simulations, the advantages, limitations, and uncertainties of these technologies were investigated.

When the assessments were initiated, the PAFC system, which has the most development experience, had reached a high level of performance and reliability in utility applications. Volume, weight, startup time, and costs were perceived as features requiring special attention for the vehicular application.

The SPE fuel cell system is also a mature technology, but mainly in aerospace applications where pure fuel and oxidant are used. In this technology, the concerns were the ability to use reformed fuel, water management, operating temperature limits, and cost.

The TFMSA system is currently an immature technology with data available only for single- and bi-cell operation, but it has the potential for improved fuel cell performance. Because of the lack of full-scale system experience, the assessment of this system could not be based on actual operating power plant data and was subject to much more conjecture than the other two systems. The same lack of information probably caused the

TABLE 1

20-kW fuel cell system characteristics — I

	Previous projections	GE SPE fuel cell	UTC adv. PAFC
Weight (lb)	680	337	550
Volume* (ft^3)	12	4.1	7
Startup time (min)	15	0	5
Operating temp range (°C)	120 - 180	0 - 104	120 - 180

*Without packing factor.

TABLE 2

20-kW fuel cell system characteristics — II

	Previous projections	GE SPE fuel cell	UTC adv. PAFC
Nominal operating point			
V/cell	0.6	0.72	0.853
A/ft^2	150	466	265
W/ft^2	90	335	226
Total electrode area (ft^2)	222	60	89
Peak power (kW)	67	66	60
Fuel cell system efficiency at 20 kW*	40%	51%	57%

*Based on higher heating value of methanol.

assessment to indicate no significant performance advantage for this system over a phosphoric acid system.

The characteristics presented for the SPE and PAFC systems and the performance levels obtained from the computer simulation using these characteristics demonstrated that fuel cells are technically viable for use as vehicular power plants. These characteristics are compared to the target system characteristics (based on 1980 PAFC power plant operational data) supplied by LANL in Tables 1 and 2.

Note (Table 1) that the SPE fuel cell system weighs less than half and has approximately one-third the volume of the target system and that the entire system can be easily placed under the hood of a GM X car. The system's ability to produce power at ambient temperature allows for virtually instant startup time. The PAFC system also falls well within the specified values, although not as dramatically as the SPE system.

In Table 2, the operating points selected, resulting electrode areas, peak power capabilities, and fuel cell system efficiencies at nominal load are given for the two fuel cell power plants. Efficiencies of over 50 percent are considerably better than the target system.

TABLE 3

20-kW fuel cell system characteristics — III

	Previous projections	GE SPE fuel cell	UTC adv. PAFC
Vehicle curb wt. (lb)	3456	2760	3188
Fuel cell wt. (lb)	680	337	550
Battery wt. (lb)	264	0	126
0 to 50 mph time* (s)	15.8	12.1	15.5
mpg of methanol*, **			
city	21.5	27.4	33.3
highway	24.2	29.7	33.6

*Curb weight plus 300 lb for passengers.
**Multiply by 2 to get gasoline equivalent.

Using the values in Tables 1 and 2 plus other necessary weight data, computer simulations were run to obtain performance data for a five-passenger vehicle (GM X car). The simulation results are shown in Table 3. In the phosphoric acid systems, batteries are required for immediate start-up. The 0 to 50 mph times are quite adequate when compared to today's compact passenger vehicles. Of most interest are the gasoline equivalent mileages, particularly the city values. Compared to the current GM X car (22 mpg city, Environmental Protection Agency estimate), the two systems offer the energy equivalent of a 60-mpg internal combustion engine vehicle for both city and highway driving.

Thus, the preliminary designs of the PAFC and SPE fuel cell systems unique to vehicular applications strongly support the technical feasibility of using fuel cells for transportation applications. Projected production costs for 100 000 units/yr fall in the range of $150 to $250/kW (1981 dollars) for both systems.

These preliminary designs were scaled up and used to assess the feasibility of fuel cell technology for providing alternatives to diesel and diesel-electric power plants in heavy-duty transportation applications, that is, the diesel-electric freight locomotive and the inland waterway push-tow boats powered by locomotive diesel engines. Preliminary results, using the energy consumption index of Btu/net ton mile for comparison, indicate that the fuel cell systems offer a significant energy savings over operation with conventional diesel power plants in locomotive application.

The fuel-cell-powered golf cart was initially completed on October 1, 1979. Hydrogen fuel for the fuel cell stack initially was supplied by carrying pressurized hydrogen in cylinders mounted on the fenders. However, the weight penalty for carrying hydrogen in the gaseous, liquid, or hydride form is fairly severe for a viable transportation vehicle.

Preliminary work on evaluating a methanol reformer furnished by the US Army Mobility Equipment Research and Development Command (MERADCOM) began in May 1981. This 6-yr-old reformer was designed by

ERC for the Army to supply 120 percent of the hydrogen requirements of a 1.5-kW stack. A properly designed reformer will convert a mixture of 1 M methanol and 1.3 M water to hydrogen and carbon dioxide with less than 0.3 percent carbon monoxide. Because the overall reaction is endothermic, a burner is usually supplied as a part of the reformer unit. The ERC reformer was designed to burn the methanol/water mix until an operating temperature near 200 °C was reached; then excess hydrogen from the stack was burned. Early experiments with this rather old reformer soon demonstrated the difficulty of predictability and reliability in establishing a controlled burn.

A new reformer was purchased from ERC and was received in October 1981. Like the first reformer, the new reformer burner as received would not generate a smooth and reliable burn, and a complete redesign of the burner subsystem began in December. A design of the fuel control system is being developed in parallel with the reformer experiments as the variables become better understood.

Electrochemical research investigations were conducted on the performance of the cathode, which is the greatest source of performance loss in the PAFC. Experiments substantiated the theory that adsorption of phosphoric acid species on the cathode is responsible for the performance losses. In contrast, very little adsorption was observed in TFMSA, which can account for improved cathode performance.

In July 1982, requests for quotes were issued for basic research efforts on electrocatalysts and membranes as suggested by the PAFC and SPE assessments. At the same time, the procurement of a state-of-the-art fuel cell system to provide experimental verification of parameters used in the computer simulations was initiated.

Plans for 1983 involve four main areas:

Electrocatalysts

This effort seeks ways to improve performance and reduce cost. In the phosphoric acid system, alloy catalysts and redox catalysts will be investigated with the objectives of increasing overload capability, increasing efficiency, and reducing catalyst cost. In particular, the use of redox catalysts to improve the performance of the cathode will be stressed. In the SPE system, reduction of the platinum loading from 8 g/ft^2 to 0.75 g/ft^2 while maintaining the base-line Nafion system performance will be emphasized. This entails animation of electrocatalyst-support interactions, electrode configurations, and electrode–electrolyte interface considerations, particularly at the oxygen electrode.

Theoretical calculations of the electronic properties of clusters of metal atoms will be made to provide insight into the behavior of electrocatalysts and provide a basis for electrocatalyst formulations.

Alternate membranes

Although the SPE technology shows significant promise in electrochemical systems, one drawback is the cost of the Nafion membrane presently in use. Nafion was selected originally because of long-life requirements in previous programs (over 60000 h). The vehicular applications, particularly the passenger car, do not require this life performance. Therefore, alternate membranes are being sought with adequate lifetimes and performance characteristics with the objective of lowering the cost from that of Nafion, $35/ft², to less than $10/ft².

Confirmation of basic research results

To guide the contractual basic research programs effectively, it is necessary to confirm results independently, determine impacts on overall system configuration, and identify new areas where research is required. LANL's basic electrochemical and modeling capabilities will be used to carry out these tasks. This will include investigating electrocatalyst performance with related kinetics and mechanisms determinations, electrode–electrolyte interface effects, the role of electrolyte functional groups in electrode kinetics, transport phenomena in electrolytes, and heat and mass balance effects. Samples of catalysts, electrodes, and electrolytes will be furnished by contractors for use in these investigations.

Verification of the vehicle computer simulation

The experimental verification of operational and interface characteristics used in the computer simulation is required to provide data for the research and development activities leading to a full-performance power plant.

In 1982, procurement of a state-of-the-art fuel cell system for use in this verification activity was initiated. Testing will be performed by connecting the fuel cell/fuel processor system to an existing electric vehicle and running the system at Los Alamos and on a dynamometer at some other installation, possibly the Jet Propulsion Laboratory. The vehicle to be used will be selected after examining data available at LANL and from other DOE electric vehicle contractors.

By measuring the performance of both the vehicle and the fuel cell systems, characteristics used in the computer simulation can be verified and the interactive effects between fuel cell/fuel processor and vehicle performance can be quantified. The use of the dynamometer provides flexibility in instrumentation and laboratory repeatability. The data obtained will be used to influence the direction of basic research efforts.

Recent publications

1 Fuel cells for transportation applications, compiled by J. R. Huff, Los Alamos National Laboratory, *Progress Report LA-9387-PR*, June 1982.