LA-UR -81-3424

MASTER

CONF-811143--1

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE: APPLICATION OF FUEL CELLS TO HIGHWAY AND NONHIGHWAY TRANSPORTATION

AUTHOR(S): J. R. Huff E-11, J. B. McCormick E-DO, D. K. Lynn E-11
R. E. Bobbett E-11, G. R. Dooley E-11, C. R. Derouin E-11,
H. S. Murray E-11, S. Srinivasan E-11

SUBMITTED TO: IGT Fuel Cells Technology Status & Applications
Chicago, IL, November 16-18, 1981

DISCLAIMER

DISTRIBUTION

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

APPLICATION OF FUEL CELLS TO HIGHWAY AND NONHIGHWAY TRANSPORTATION

James R. Huff, J. Byron McCormick, David K. Lynn,
Ronald E. Bobbett, G. Richard Dooley, Charles R. Derouin,
Hugh S.Murray, and S. Srinivasan
Project Leader, Fuel Cells for Transportation Applications
Los Alamos National Laboratory
Los Alamos, New Mexico, 87545

ABSTRACT

Transportation is the nation's largest single energy user and accounts for approximately 50% of our current petroleum consumption. This fact not only defines the urgency of the problem, it also delineates the magnitude of the infrastructure already in place and the built-in inertia of the system. Major changes in our modes of transportation will not take place instantly, as we might wish, but will certainly require years and, perhaps, decades of steady evolution and technological development.

Fuel cells are a promising alternate power source for transportation applications for a number of reasons. Modeling studies have indicated the potential for providing highway vehicles with performance and range comparable to those provided by internal combustion engines. Fuel cells are efficient and therefore reduce energy consumption. They are nonpolluting in terms of both air and noise pollution - highly desirable features for urban applications. In addition, they can operate on nonpetroleum fuels such as hydrogen or hydrogen in combined form, for ex 'e, methanol or ammonia, thereby reducing the nation's petroleum dependency.

The investigation of the application of fuel cells to the highway transportation described began in 1977. Recently, the scope was broadened to include a determination of the feasibility of using fuel cells in nonhighway transportation, i.e., rail and marine.

APPLICATION OF FUEL CELLS TO HIGHWAY AND NONHIGHWAY TRANSPORTATION

INTRODUCTION

During the past decade, the advent of the energy "crisis" and the growth of ecological concerns have presented both a major challenge and an opportunity for technologists and engineers. This is particularly true in the United States because of the worldwide impact of our energy policy (5% of the world's population using more that 35% of the world's energy). Within this framework, the development of more energy efficient modes of transportation assumes a particularly critical role in future energy scenarios. Transportation is the largest single energy user and accounts for approximately 50% of our current petroleum consumption. Of this total, over one-half is used in passenger automobiles and approximately one-quarter is attributable to trucks and buses. The remainder is consumed in nonhighway transportation applications.

As a result of the significant progress being made in fuel cell techrology in DOE, EPRI, GRI, and DoD programs, fuel cells are being considered as a promising alternate power source for transportation applications for a number of reasons (1,2,5,7,9-15). Modeling studies have indicated the potential for providing highway vehicles with performance and range comparable to those powered by internal combustion engines. Fuel cells have a high efficiency at all power ratings, only beginning to show reduced efficiency at about 20 kW. In addition, they have a high efficiency at part load over a range from 20% to 100% of rated output. Fuel cells can operate on nonpetroleum fuels such as hydrogen or those containing hydrogen in a combined form, for example, methanol or ammonia. Methanol was the fuel of choice for the highway transportation applications because it offered a low temperature of fuel processing, which led to both the smallest fuel processing package and better thermal integration of the overall system. Fuel cells are nonpolluting in terms of both air and noise pollution - highly desirable features for urban applications.

The foregoing were all derived from stationary power plant data. The Army power plant program should provide information on the possibility of low maintenance in mobile applications and also, via shock and vibration tests, give some indications about safety aspects.

HIGHWAY TRANSPORTATION

In the DOE highway vehicle transportation program, four fuel cell technologies are being considered; these are phosphoric acid electrolyte, solid polymer electrolyte, super acid electrolyte, and alkaline electrolyte.

Two tools have been developed to aid in evaluating fuel cells in transportation applications. The first was a fuel-cell-powered golf cart that is used to understand system component interfaces. The second was a fuel cell/battery vehicle simulation program developed to perform vehicle analysis. A detailed analysis of component operation and interaction, in terms of voltage, current, fuel consumption, torque, and angular velocity as a function of time, is used to calculate the vehicle's performance and fuel consumption for each drive cycle specified. In the analysis, design tradeoffs can be made on the fuel cell power system to improve vehicle performance or to reduce the size and cost of the fuel cell.

Two vehicles, the consumer vehicle and the city bus, have been subjected to in-depth analysis. In each case, a target fuel cell and an advanced fuel cell were used. The target fuel cell was characterized by a 15-minute start-up requiring 260 pounds of batteries, weights of 2.4 lb/ft^2 of electrode and 7.4 lb/kW for the reformer and auxiliaries; 300 W/ft^2 maximum power density; and methanol-water premix fuel. The advanced fuel cell assumed ambient temperature operation capability thereby eliminating the start-up battery requirement; increased cell voltage and reduced internal impedance; the same weights as the target system; and 800 W/ft^2 maximum power density.

Consumer Vehicle

The consumer vehicle analysis is based on the body and chassis of the General Motors X car. The drive train retained the 4-speed manual transmission, but the final drive ratio was changed to meet design requirements. The target fuel cell system for the consumer car is described in Table 1. Performance of the car with low and high power density fuel cells is shown in Table 2. By comparison, the normal X car has a curb weight of 2900 lb (300 lbs for passengers) and EPA estimated mileages (non-California, 1981) of 22 mpg on the urban driving schedule (UDS) and 35 mpg on the highway driving schedule (HDS). It is interesting to note that the miles per gallon of methanol is almost the same for the UDS and HDS. This is a function of the part load efficiency of the fuel cell. The advanced fuel cell system for the car and performance are given in Tables 3 and 4, respectively. The UDS ranges for both the target and advanced cases are for 20 gallons of methanol.

City Bus

The city bus has some significant advantages for an early vehicular application of fuel cells. These include centralized maintenance; centralized refueling; larger volume to work with; and million-mile life, which, when coupled with life cycle costing and maintenance considerations, becomes an important cost item. In addition, noise and pollution become overwhelming criteria when major cities become involved. Target and advanced fuel cell systems for the city bus are itemized in Table 5. Calculated performance data for the two systems are given in Tables 6 and 7, respectively.

NONHIGHWAY TRANSPORTATION

Nonhighway transportation concepts have included marine, aircraft, rail, and pipeline prime movers (3,4,6,8). Aircraft and pipeline uses do not appear to be feasible. The marine and rail power plants are in the megawatt range, which is more akin to utility sizes than those used for the highway vehicles.

Initial efforts have begun at Los Alamos toward identifying the characteristics of heavy duty freight locomotives, push-tow boats, and fuel cell systems in order to determine whether or not fuel cell power plants are feasible for use in heavy duty rail and inland waterway marine transportation. Modifications to the existing fuel cell vehicle simulation code have begun so the analysis on trains and push-tow boats can be accommodated.

Rail Applications

It has been established that the current freight locomotive design power is 3000 hp (2237 kW). The most recent power plant designs are in the 3500 to 3600 hp range (2610 to 2685 kW), but there is no trend to higher horsepower models as was forecast 10 years ago. Power plant specific weights are in the range of 22 lb/kW for the diesel engine, alternator, and cooling equipment; and there is on the order of 1 ft^3/kW of space available in typical locomotives for the power plant. Various fuel cell power plant capabilities are presently being matched to these parameters. The initial prognosis is that future fuel cell power plants will be within the size and weight constraints for diesel electric locomotives.

Marine Applications

There is a much wider power range in use for push-tow boat diesel power plants (1000 to 6000 hp). However, the trend is toward the 6000-hp boat as the mainstay of heavy duty inland waterway transportation. These boats will use twin 3000-hp locomotive diesels. Thus, the 3000-hp (2237 kW) power plant is an appropriate standard for the fuel cell investigation.

Two interesting concepts for marine use of fuel cells involve submarines (4,8). In the first, fuel cells have been suggested as a possible power plant for a submarine MX missile base. The idea is that the fuel cell could reduce detectability and, hence, vulnerability. The second proposes the use of fuel-cell-powered submarine tankers for use where surface commercial shipping is energy expensive.

ACKNOWLEDGMENTS

The Los Alamos National Laboratory investigations described were supported by the Department of Energy Offices of Vehicle and Engine Research and Development and Energy Systems Research.

REFERENCES CITED

1. Appleby, A. J. and Kalhammer, F. R., "The Fuel Cell: A Practical Power Source for Automotive Propulsion?" Drive Electric 80, Wembley, London, England, October 14-17, 1980.

2. Bobbett, R. E., McCormick, J. B., Lynn, D. K., Derouin, C. R., Salazar, P. H., and Kerwin, W. J., "Fuel-Cell-Powered Golf Cart," Electric Vehicle Expo '80, St. Louis, Missouri, May 20-22, 1980.

3. Cart, E. N., Jr., editor, "Alternative Energy Sources for Non-Highway Transportation," Exxon Research and Engineering Company, Report DOE/CS/05438-TI on DOE Contract No. DE-AC05-77CS05438.

4. Drell, S. D. and Garwin, R. L., "Basing the MX Missile: A Better Idea," Technology Review, p. 20, May/June 1981.

5. Escher, W. J. D. and Foster, R. W., "An Assessment of the Status of Fuel Cell/Battery Vehicle Power Systems," Brookhaven National Laboratory Report 51210 (February 1980).

6. Kamalian, H., "Fuel Cell/Battery Powered Trains," Abstracts, National Fuel Cell Seminar, Norfolk, Virginia, June 23-25, 1981.

7. Kordesch, K. V., "City Car With H_2-Air Fuel Cell/Lead Battery," Proc. Intersociety Energy Conversion Conference, 1972, p. 103.

8. Kumm, W. H., "Fuel Cell Propulsion for Marine Systems," Abstracts, National Fuel Cell Seminar, Norfolk, Virginia, June 23-25, 1981.

9. Lynn, D. K., McCormick, J. B., Bobbett, R. E., Derouin, C. R., and Kerwin, W. J., "Fuel Cell Systems for Vehicular Applications," SAE Congress and Exposition, Detroit, Michigan, February 25, 1980, SAE Technical Paper Series 800059.

10. Lynn, D. K., McCormick, J. B., Bobbett, R. E., Srinivasan, S., and Huff, J. R., "Design Considerations for Vehicular Fuel Cell Power Plants," Proc. Sixteenth Intersociety Energy Conversion Engineering Conference, 1981, p. 722.

11. McBreen, J., Taylor, E. J., Kordesch, K. V., Kissel, G., Kulesa, F., and Srinivasan, S., "Fuel Cell Technologies for Vehicular Applications," Brookhaven National Laboratory Report 51047 (May 1979).

12. McCormick, J. B., Bobbett, R. E., Lynn, D. K., Nelson, S., Srinivasan, S., and McBreen, J., "Application of Fuel Cells in Transportation," Proc. Fourteenth Intersociety Energy Conversion Engineering Conference, August 5-10, 1979, p. 613.

13. McCormick, J. B., Bobbett, R. E., Srinivasan, S., and McBreen, J., eds., "Proceedings of the Fuel Cell in Transportation Applications Workshop - August 15-17, 1977," Los Alamos National Laboratory Report LA-7270-C (July 1978).

14. McCormick, J. B. and Huff, J. R., "The Case for the Development of Fuel-Cell-Powered Vehicles," Technology Review, p. 54, August/September 1980.

15. McCormick, J. B., Huff, J. R., Srinivasan, S., and Bobbett, R. E., "Applications Scenario for Fuel Cells in Transportation," Los Alamos National Laboratory Report LA-7634-C (February 1979).

Table 1. Target Fuel Cell System for Consumer Car

Nominal 20 kW, 96 V

	Low Power Density	High Power Density
Operating Point (V/Cell)	0.6	0.5
Power Density (W/ft^2)	90	219
Peak Power (kW)	66	27
Efficiency at 20 kW* (%)	42	35
Total Electrode (ft^2)	222	91
Weight (lb)	680	366

*Based on high heating value

Table 2. Performance of Consumer Car With Target Fuel Cell

	Low Power Density	High Power Density
Weight[1] (lb)	3756	3442
Top Speed (mph)	67.8	66.7
0-50 mph Time (sec)	15.8	17.7
Mpg of Methanol[2]		
UDS	21.5	17.8
HDS	21.9	19.3
UDS Range (miles)	430	356

[1]Curb Weight + 300 lb

[2]Multiply by 2 to get gasoline equivalent

Table 3. Advanced Fuel Cell System for Consumer Car

Nominal 20 kW, 96 V

Operating Point (V/Cell)	0.74
Power Density (W/ft^2)	22
Peak Power (kW)	72
Efficiency at 20 kW (%)	52
Total Electrode Area (ft^2)	91
Weight (lb)	366

Table 4. Performance of Consumer Car With Advanced Fuel Cell

Weight[1] (lb)	3168
Top Speed (mph)	67.4
0-50 mph Time (sec)	14.1
Mpg of Methanol[2]	
UDS	30.6
HDS	32.8
UDS Range (miles)	612

[1]Curb weight + 300 lb

[2]Multiply by 2 to get gasoline equivalent

Table 5. Fuel Cell Systems for a City Bus

Nominal 120 kW, 576 V
Six 20-kW modules in series

	Target	Advanced
Operating Point (V/Cell)	0.6	0.74
Power Density (W/ft^2)	90	222
Peak Power (kW)	396	432
Efficiency at 120 kW (%)	42	52
Total Electrode Area (ft^2)	1333	540
Weight (lb)	4087	2184

Table 6. Performance of 40-ft City Bus With Target Fuel Cell

Weight with 48 Passengers (lb)	33,667
Hotel Load (kW)	15
Methanol Consumption[1] (mpg)	
Central Business District	2.0
Arterial	2.1
Commuter	3.0
Composite	2.2

Meets DOT top speed, acceleration, gradeability, and weight requirements (6/80)

[1]Multiply by 2.17 to get diesel equivalent

Table 7. Performance of 40-ft City Bus With Advanced Fuel Cell

Weight with 48 Passengers (lb)	31,764
Hotel Load (kW)	15
Methanol Consumption[1] (mpg)	
Central Business District	2.5
Arterial	2.7
Commuter	3.8
Composite	2.8

Meets DOT top speed, acceleration, gradeability, and weight requirements (6/80)

[1]Multiply by 2.17 to get diesel equivalent