THE ROAD AHEAD FOR FUEL CELL CARS (WITH A LOOK IN THE REARVIEW MIRROR)

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Sustained efforts to develop fuel cells for power generation have occurred in three "waves". The first one, in the 1960s, developed fuel cells for the space program, providing the bulk of the electric power on-board the Gemini and Apollo missions, including the manned missions to the moon. Fuel cells operating on hydrogen and oxygen continue to provide the electrical needs of the Space Transport System vehicles. The second wave, in the 1970s, sought to develop fuel cells as clean, efficient generators of utility electric power, initially meant to be fueled with coal gas, and more recently with natural gas. The third wave of fuel cell development, begun in the late 1980s and continuing very actively today, is focused on their application to light- and heavy-duty vehicles, as well as small stationary and portable power applications. Along the way, several demonstration fuel cell vehicles were also built, including a tractor, forklift truck, bicycle, golf cart, van, and passenger car. This paper discusses the development of fuel cells for transportation applications, primarily over the past decade or so.

WHY FUEL CELLS FOR TRANSPORTATION

From the perspective of public policy, the impetus for government funding of fuel cell R&D for transportation had three drivers: high efficiency, low to zero emissions, and energy security (operation on indigenous fuels). Futurists also see fuel cells as an integral part of the inevitable "hydrogen economy" of the not too distant future. Fuel cells operating at cell voltages of 0.7–0.85 V offer cell-level efficiencies of 56–68% (based on the lower heating value, LHV, of hydrogen), and system-level efficiencies of 35–60% (depending on the on-board fuel and system configuration). These values may be compared with the 33–37% peak efficiencies of advanced gasoline engines. With hydrogen as the on-board fuel, fuel cell vehicles will have zero emissions (other than clean, even potable, water); with other on-board fuels, emissions of regulated pollutants are projected to be very low. The viable choice of fuels for transportation fuel cells is limited, in one sense to hydrogen, but in a broader sense, to any fuel that can be converted to hydrogen, in an on-board or off-board fuel processor.

WHICH FUEL CELL(S) FOR TRANSPORTATION

The overwhelming majority of automotive fuel cell development activity is based on the polymer electrolyte fuel cell (PEFC). Prototype vehicles have also been built using alkaline, phosphoric acid, and direct methanol fuel cells, including a solid oxide fuel cell based auxiliary power unit. For general-purpose cars, vans, and buses, however, all of the major worldwide automobile manufacturers have fielded several different vehicles powered by the PEFC. Major reasons for choosing the PEFC are a solid electrolyte, high performance (power density, efficiency), and ability to generate useful power at 0˚C or even lower, yielding nearly instantaneous startup if hydrogen is the on-board fuel. Several PEFC developers have near-commercial fuel cells of from 1 to 100 kW. In contrast, there is only a limited number of developers and vendors of the other types of fuel cells (for automotive or other applications).

CHALLENGES YET TO BE MET

There are still several challenges that must be overcome and issues that must be resolved before automotive fuel cells can become commercially successful. A major unresolved issue is the choice of fuel for fuel cells. The PEFCs need hydrogen (although direct electrochemical oxidation of methanol and ethanol is also being pursued). The introduction of hydrogen for general automotive use has yet to meet two challenges: how to store enough of it on-board the vehicle to achieve the required range, and how to produce and distribute the hydrogen to the public. Gasoline or other liquid fuels would be attractive to the consumer, but reforming such fuels to clean hydrogen on-board a vehicle is technically difficult, and it may necessitate a hybrid rather than a stand-alone fuel cell power system.

A second major challenge to the mass introduction of fuel cell vehicles is the high cost of fuel cell systems. Although these costs are expected to decrease substantially with continuing development and increasing volumes of production, the projected costs of $200–300/kW for mature, high-volume manufacturing are still more than an order of magnitude greater than those of today's gasoline or diesel engines.

Other desired developments include: higher power density, particularly for reformate-fueled systems; compact, rapid-start fuel processors for carbonaceous fuels; lower weights, volumes, and complexity of the heat and water management subsystems; higher efficiencies and lower costs of power electronics and electric drive components; and lower cost/higher performance energy storage and regenerative braking subsystems for hybrid power system architectures.

RECENT AND ONGOING DEVELOPMENTS

This past decade of automotive fuel cell development opened with the unveiling of the hydrogen-fueled PEFC Ballard bus (1993), followed shortly thereafter by the three methanol-fueled phosphoric acid fuel cell DOE/ Georgetown University buses (beginning in 1994). Prototype cars, vans, and buses were built in quick succession by DaimlerChrysler, Toyota, Mazda, Nissan, Ford, Honda, General Motors, Hyundai, and other major automobile manufacturers. Demonstrations of hydrogen-fueled fuel cell buses are being planned for several major metropolitan areas all around the world. The first significant introduction of fuel cell vehicles is likely to be as hydrogen-fueled fleets. These may be followed by more widespread liquid-fueled vehicles if fuel processor development is successful, and beyond that, by even more numerous hydrogen-fueled vehicles when the hydrogen economy becomes viable.

Currently, the major R&D activity at Argonne and elsewhere is in the areas of fuel processors and catalysts; improved materials (anodes, cathodes, electrolyte membranes, bipolar plates, heat transfer media); air, water, and heat management; and hydrogen storage materials and processes. Assessments of projected costs and various market studies are also being undertaken.