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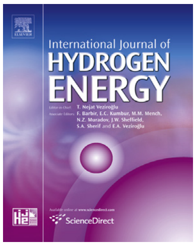

Fuel cells: Optimism gone – Hard work still there☆

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ABSTRACT

A brief overview of the progress in fuel cell applications and basic technology development is presented, as a backdrop for discussing readiness for penetration into the marketplace as a solution to problems of depletion, safety, climate or environmental impact from currently used fossil and nuclear fuel-based energy technologies.

1. Introduction

The goals for commercialisation of fuel cell technologies set some ten years ago have not been met at present, and the goals set then for the upcoming decade seem equally unattainable. Despite this the future of hydrogen and fuel cell technologies still retains great hopes. The failure of the early commercialisation was due to a belief that dates for achieving scientific goals could be set by company management. This was false: scientific advance takes time and ingenuity, and pouring in money does not guarantee success. The present phase is one of allowing scientific work to precede presentations of new demonstration fleets of vehicles. Not only must cost be reduced and efficiency raised, but the lifetime of cells has to reach not only the 5000 h of operation specified by initial goal specifications, but the higher figures needed if replacement of fuel cells should not be required several times during the lifetime of a vehicle. For passenger cars, lifetimes above 15 years are today standard, and extended values would be preferable due to materials and environmental considerations. The positive appraisal offered after all is founded on the fact that fuel cell development has not been given up, but shifted from emphasis on showroom zero-series vehicles to allowing in-depth investigations of problems such as those mentioned above to be carried out and discussed in the broader scientific community. The number of scientific papers on fuel cells appearing in peer-reviewed journals is much higher today than it was 5–10 years ago, indicating that the number of people trying to find solutions to outstanding problems has not decreased. The following sections will provide an overview of current fuel cell efforts, a case study of competing options for road vehicles, and finally some remarks on cost and time-wise prospects for implementation.

Acronyms: EV, electric vehicle; FC, fuel cell; PEM, proton exchange membrane; MCFC, molten carbon fuel cell; DMFC, direct methanol fuel cell; SOFC, solid oxide fuel cell; UPS, uninterrupted power supply; CPH, combined power and heat; GPS, geographical positioning system.

☆ This paper was presented as an introductory overview lecture at the 2011 Hypothesis Conference. It is based on the 2nd edition of the author's *Hydrogen and Fuel Cells*, published by Elsevier December 2011, where more detailed analysis supporting the conclusions drawn here may be found.

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2. Short overview of fuel cell application technology

2.1. *Road vehicles*

Present focus is largely on *hybrid* fuel cell/battery systems. Choosing to deliver power directly from the fuel cell to the electric engine (termed *parallel operation*) is one option, another being to deliver the power from the fuel cell through the battery (*serial operation*). In any case, the hybrid concept allows the rating of the fuel cell to be below that of the motor. Equipment mass is an important parameter, as indicated by the examples presented in Table 1.

2.2. *Performance modelling*

Extensive modelling of PEM fuel cell performance has been made [2,3], based on a selection of small efficient cars illustrating a pure fuel cell (FC) design, a pure electric vehicle (EV) and several hybrid vehicles such as those described in Table 1. Comparison is further made with the same vehicle propelled by a common-rail diesel engine as currently used in most small passenger cars in Europe (typically some 20% more energy efficient than a similar car with gasoline engine).

The simulations are employing a mixed driving cycle put together from pieces of the driving cycles used in the United States and in the European Union for regulatory and taxation purposes, and containing both highway driving, suburban stretches, and city driving with frequent stops at red lights.

Table 2 shows by modelling a range of hybrid cars that lower than 20 kW fuel cell rating leads to insufficient battery charging, implying that the vehicle cannot be electrically autonomous, but has to obtain battery recharging from an external source, which describes a *plug-in hybrid* vehicle. Recharging of batteries can be done when the car is parked at a suitable power outlet (home garage, working place, or a public recharging station). The electricity cost is typically smaller than that of hydrogen, but both are required for a plug-in hybrid, as long as reversible fuel cell operation is not implemented. Fig. 1 illustrates the results of Table 2.

2.3. *Other transport modes*

Early interest concentrated on larger vehicles, such as buses, because the fuel cell equipment was bulky and because such vehicles traverse fixed routes, allowing hydrogen to be dispensed from a limited number of sites. The use of fuel cells in these and other types of vehicles, including ships, trains, and aircraft, which are described in reference [3], still offer promising market areas.

Table 1 – Characteristics of vehicles modelled [1].

Component mass (kg)	Pure FC	Hybrid	Pure EV
Basic vehicle (incl. Li-ion start battery)	570	570	570
Fuel cell equipment[a] (40, 20 and 0 kW)	150	100	0
Exhaust management	8	5	0
Li-ion batteries (0, 15 and 250 MJ)	0	70	1134
Electric motor (50 kW)	60	60	60
Transmission (manual 1-speed equivalent)	50	50	50
Passengers and cargo (average)	136	136	136
Total	974	991	1950

[a] Including mass of 60% filled hydrogen storage tank.

Table 2 – Summary of results for hybrid fuel cell-battery vehicle simulations [2,3].

Plug-in hybrids:					
Fuel cell rating (kW)	0	5	10	15	
Fuel cell system mass (kg)	0	43	55	68	
Fuel cell energy use (MJ/km)	0	0.435	0.666	0.751	
Battery capacity (MJ)	250	125	57.5	25	
Battery system mass (kg)	1136	567	261	113	
Battery fuel use (MJ/km)	0.617	0.263	0.1	0.028	
Battery recharging range (km)	405	468	574	890	
Self-recharging hybrids:					
Fuel cell rating (kW)	20	25	30	35	40
Fuel cell system mass (kg)	80	93	105	118	130
Fuel cell energy use (MJ/km)	0.796	0.809	0.818	0.842	1.138
Battery capacity (MJ)	15	10	10	7.5	0
Battery system mass (kg)	68	45	45	34	–

2.4. *Applications in power plants and for stand-alone systems*

For large-scale, stationary power generation one can use either low- or high-temperature fuel cell systems. The overall systems may employ PEMFC, MCFC, or SOFC, and will further need facilities for fuel preparation and exhaust cleaning. The detailed discussion of components and possible market entrance scenarios in [3] suggests that hydrogen might find an early application in connection with centralised power stations, using gas turbines rather than fuel cells and serving mainly to smooth the variability introduced in electric power systems employing intermittent renewable resources such as wind or photovoltaic converters.

2.5. *Building-integrated systems*

Building-integrated fuel cell systems may evolve as a natural extension of current efforts to replace natural gas boiler units by co-producing power-and-heat units, eventually replacing natural gas fuel by hydrogen. Such technologies constitute the largest components of a new fuel cell subsidy program implemented in Japan after the Fukushima nuclear accident. Already more than 10 000 co-generating fuel cell units rated at 0.75–1 kW have been installed [4]. The direct purpose of this policy measure is to replace demand on peak electric power from remaining nuclear plants.

In a next phase, use of reversible fuel cells could alleviate the need for hydrogen pipelines reaching each building, and could further expand the electricity plus heat supply by fuel production for a resident vehicle. The electricity supply for the reversible fuel cell could be excess power from variable renewable sources such as wind or solar electricity.