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Hydrogen Fuel Cell Battery Electric Vehicles (HFCBEV) *vs.* Battery Electric Vehicles (BEV) – *A Birmingham Experience*

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This paper describes the development, design, testing and commissioning of five HFCBEVs on the University of Birmingham campus (Figure 1). The HFCBEVs were tested to evaluate performance, range, efficiency and system cost and were compared to 'pure' lithium-ion BEVs (Mitsubishi iMiEV, 47 kW electric motor, 58 MJ of battery storage, 1100kg, £26,700 – Figure 2) and conventional internal combustion engine (ICE) diesel vehicles. The 11 kW electric motor in these HFCBEVs were powered directly by an inexpensive 1.5 kWh lead acid battery pack (£1,000) which was constantly charged up by a 1.2 kW Proton Exchange Membrane (PEM) fuel cell (Ballard Nexa, £4,000) running on a 350 bar hydrogen composite tank (Class III, Dynecell, Dynetek Industries, £4,000). The electrolytic grade hydrogen (99.999%, Green Gases Ltd) was delivered by an Air Products refueller (Series 100) and refuelling 0.6kg of hydrogen took an average of 3-5 minutes (for). The hydrogen consumption of the HFCBEVs was 10.0 $g.km^{-1}$, giving an energy efficiency of 0.71 $km.MJ^{-1}$ (77 mpg of diesel equivalent) with up to 60 km range on full throttle with an acceleration of 1.5 $m.s^{-2}$ and a top-speed of 30 mph (note that 80 km range would require either 0.94 $km.MJ^{-1}$ or a 0.8 kg hydrogen tank). The weight of the HFCBEVs is 525 kg with a load capacity of 200 kg.

The BEVs showed better efficiency (2.22 $km.MJ^{-1}$) with higher range (up to 130 km) and speed (80 mph) to that of the HFCBEVs. Overall, all hydrogen and 'pure' BEVs offered better efficiency and performance than ICE diesel vehicles. Finally, we clearly demonstrated that hydrogen PEM Fuel Cell can be used as an 'effective' range extender when used with some batteries. This paper reports the early results of these tests and follows from two previous publications [1,2].

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Figure 1: Hydrogen Fuel Cell Battery Electric Vehicles at The University of Birmingham (UK).

Figure 2: Battery Electric Vehicles (Mitsubishi iMieV) at The University of Birmingham campus (UK).

1 Introduction

In the UK, there is a substantial problem of increasing energy use in transport which takes about 30% of total energy usage, mainly fossil fuel based, with large CO2 emissions. Since North Sea oil and gas reserves have now been depleted, UK consumption exceeds the oil extracted. To diversify transport fuel is therefore a priority and two steps are being taken to use renewables:

1. To employ BEVs charged from the existing electricity grid;
2. To develop HFCBEVs to be refuelled from green hydrogen gas refuelling stations.

Currently, 110 BEVs are being tested in a project which started in 2009 and which runs through 2011 - the TSB funded CABLED [3] project (Coventry and Birmingham Low Emission Demonstrator). In addition, HFCBEVs have been tested on the University of Birmingham campus since 2008 and 8 further vehicles will be tested later in 2010.

Hydrogen fuel cell hybrid vehicles have been explored theoretically in a number of previous papers [4,5] but most operational hydrogen hybrids have been combustion which continue to emit NOx. The purpose of this study was to introduce a new design of lightweight hydrogen fuel cell hybrid on campus and to compare the hydrogen vehicles with ‘pure’ lithium ion battery electric vehicles.

2 Vehicles tested and Results

The HFCBEVs were designed with a fuel cell battery charger which topped up the lead acid accumulator when the vehicle was idle (Figure 3).

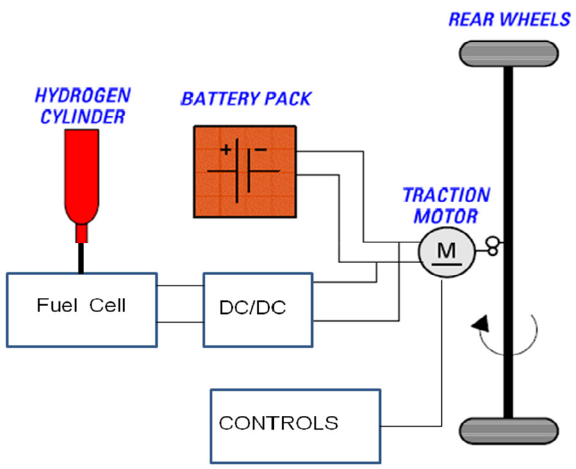

Figure 3: Mechanical drive system layout.

3 Characteristics of the PEM Fuel Cell stack

The 1.2kW Ballard Nexa PEM fuel cell was used, as it was compact and relatively low cost, and provided the durability required for the demanding operating environment. The stack efficiency quoted by Ballard was 38% (LHV) at full power and 48% at half power inclusive of parasitic loads. This was consistent with measurements taken from the stacks installed into the vehicle fleet. Table 1 below shows the characteristics of the 1.2kW Ballard Nexa. The Nexa fuel cell system is designed for operation on pure gaseous hydrogen. No fuel humidification is required. Hydrogen can be supplied at pressures ranging from 0.7 to 17 bars (gauge).

Table 1: Characteristics of the PEMFC stack.

Nominal power (at 0.55V per cell)	1200W
Heat dissipation	1600W (at rated net power)
Nominal operating point	26V (DC) x 46A (DC)
Efficiency (full load)[a]	32%
(50% load)	41%
Mass	13kg
Lifetime	2000 hours
Anode gas	99.999% H_2
Consumption (at full power)	17.5 SLPM
Pressure / Temperature / Humidity	7 to 17.2 bar/3-40^{o}C/0% -95%
Water emission	870ml/h (max)
Noise	72 dBA @ 1m

Overall, fuel cell reliability has been excellent to date, providing over 2,000 hours of operation across the fleet and 2,000 km travelled with no technical problems or observable degradation. Experimental *V-I* curves for the stacks in four of the vehicles are shown in Figure 5, and demonstrate that the PEM fuel cell performance is consistent between stacks and against manufacturer's specifications – despite incidences of fuel starvation, excessive current draw, rapid power cycling, ambient temperature extremes and vibration/shock received during operation.

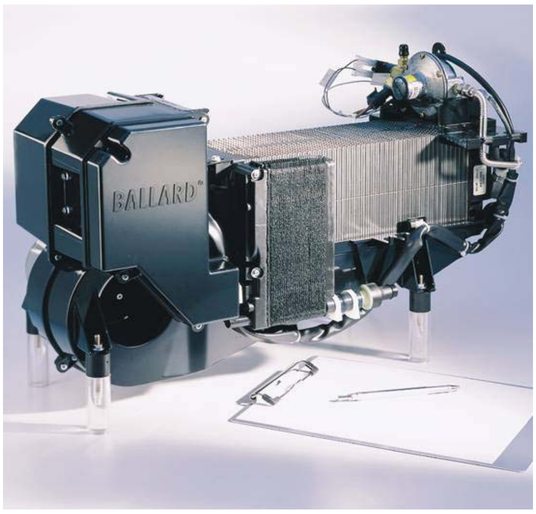

Figure 4: 1.2 kW PEM Fuel Cell Stack Ballard Nexa used in the five HFCBEVs.

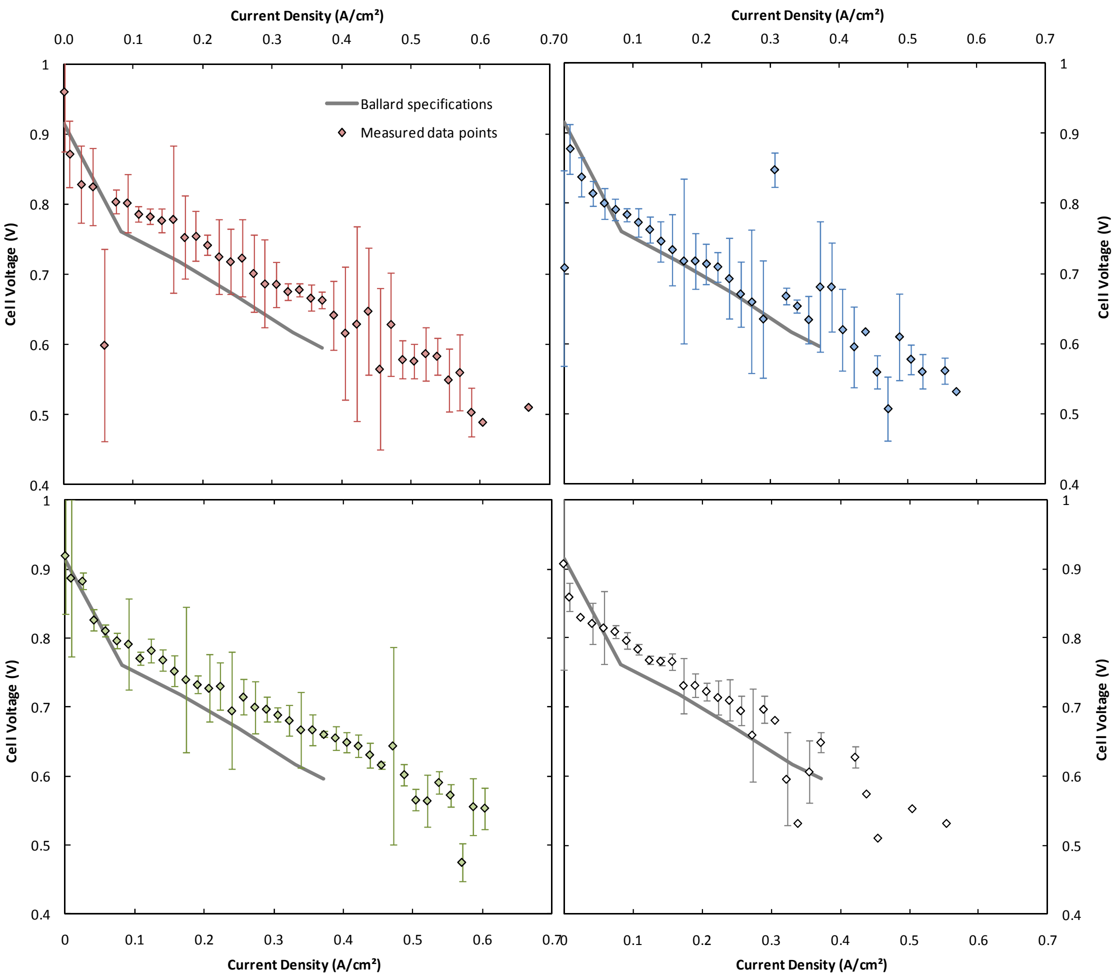

Figure 5: *V-I* curves taken from the Ballard Nexa stacks installed in each HFCBEV.

***Keywords**:* hybrid vehicle; hydrogen PEM fuel cell; 350 bar hydrogen; battery electric vehicle (BEV)

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