Journal of Power Sources 269 (2014) 975–993

Contents lists available at ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

Review

Status of hydrogen fuel cell electric buses worldwide

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HIGHLIGHTS

- Fuel cell electric buses worldwide: North America and Europe.
- Performance metrics: miles, availability, fuel economy, fuel cost, roadcalls, hydrogen refueling.
- Hydrogen refueling infrastructure.
- Fuel cell technology.
- Projections and targets for fuel cell electric buses.

ARTICLE INFO

Article history:
Received 24 March 2014
Received in revised form
9 June 2014
Accepted 10 June 2014
Available online 31 July 2014

Keywords:
Fuel cell electric bus
Fuel cell technology
Hydrogen refueling
Hydrogen infrastructure
Public transportation

ABSTRACT

This review summarizes the background and recent status of the fuel cell electric bus (FCEB) demonstration projects in North America and Europe. Key performance metrics include accumulated miles, availability, fuel economy, fuel cost, roadcalls, and hydrogen fueling. The state-of-the-art technology used in today's fuel cell bus is highlighted. Existing hydrogen infrastructure for refueling is described. The article also presents the challenges encountered in these projects, the experiences learned, as well as current and future performance targets.

1. Introduction

For years, developed countries have made great strides toward improving air quality in densely populated metropolitan cities and advocated the need to use alternative energy sources to petroleum as the pathway toward reducing transportation-related air pollution. Heavy-duty vehicles, especially electric busses powered by hydrogen fuel cells will be an important element in any plan to achieve the targets for air quality and pollution reduction.

There are numerous operational, environmental and economic benefits of fuel cell electric buses (FCEBs) over traditional diesel or diesel hybrid busses. FCEBs are more fuel efficient [1] as shown in Fig. 1. These buses operate with no local emissions, reduced noise, and a substantial reduction in greenhouse gas emissions on a well-to-wheel basis without some of the performance, range and route flexibility issues seen in other zero emission technologies [2]. Use of fuel cells for transit reduces dependence on petroleum and adverse effects of price fluctuations. For these reasons, FCEBs are progressing towards commercialization and the number of FC bus and FC manufacturers are increasing steadily (Fig. 2). With about 100

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http://dx.doi.org/10.1016/j.jpowsour.2014.06.055
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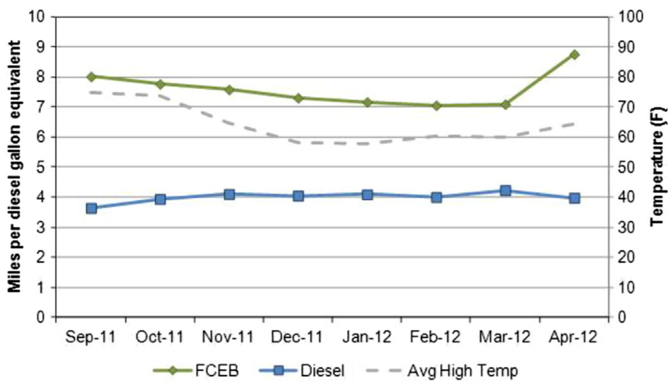

Fig. 1. Average fuel economy for the fuel cell and diesel buses [1].

buses on the road in demonstration projects across the globe, FCEBs are approaching government and transit agency targets in technical performance, durability and reliability. There remain, however, a few barriers to reaching full commercialization of FCEBs. The major barriers include durability of the fuel cell power systems, the relatively high initial capital cost of fuel cell buses, and the availability and cost of hydrogen. These barriers will be overcome with continuing improvement in fuel cell technology, high volume manufacturing, and establishment of large refueling facilities (1000 kg day^{-1}). Table 1 [3] summarizes current active FCEBs in the world. The majority of them are located in North America and Europe. Collectively, they have accumulated over 3 million miles of successful operation.

In the United States, the Federal Transit Administration established the national Fuel Cell Bus program in 2006 to advance the commercialization of FCEBs. The program has provided nearly $90 million since 2006 to promote the development and testing of cleaner, greener sources of fuel for the transit industry. As of August 2013, there are 18 active FCEBs in demonstrations at six locations [4]. Fourteen of the 18 busses are in the state of California. This review summarizes data collected for the data period from August 2012 to July 2013 from five different FCEB demonstrations at four transit agencies. These include 12 Van Hool buses with ClearEdge.

Power (formerly UTC Power) fuel cells (ZEBA) at AC Transit, Oakland, CA; 4 Van Hool buses with ClearEdge Power fuel cells (Nutmeg) at CTTRANSIT, Hartford, CT; 1 New Flyer bus with Ballard fuel cell and 1 Eldorado bus with Ballard fuel cell at SunLine, Thousand Palms, CA; and 1 Proterra bus with Hydrogenics fuel cell at Capital Metro, TX.

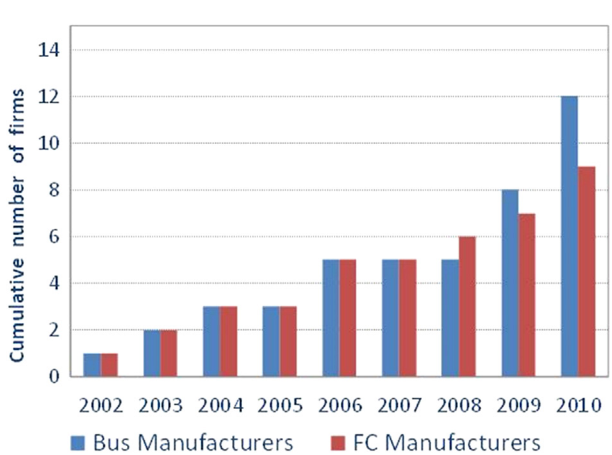

Fig. 2. Number of competitors in the fuel cell bus market [2].

In Europe, the HyFLEET-CUTE demonstration project with 30 full size Daimler buses in 10 cities accumulated 1.3 million miles between 2003 and 2010 [5]. These buses were battery dominant with 12 kW Hydrogenics fuel cells. Building on the HyFLEET-CUTE success, the European fuel cell bus CHIC (Clean Hydrogen in European Cities [6]) demonstration projects currently has 26 FCEBs in Phase 1 operating in 5 countries: 5 Daimler buses with AFCC fuel cells in Switzerland, 5 Van Hool buses with Ballard fuel cells in Norway, 8 Wrightbus buses with Ballard fuel cells in the United Kingdom, and 8 Daimler busses with AFCC fuel cells in Italy. This fleet will run from 2011 to 2017 with the aim to achieve a number of performance targets which will ease the integration of the technology into today's public transport standards. The CHIC projects are supported and funded by the Joint Technology Inititatives' (JTI) Fuel Cell and Hydrogen Joint Undertaking (FCH-JU) and a set of industry partners.

Additionally, the High V.LO City project [7] in Europe is deploying 14 FCEBs (all Van Hool busses) in 3 countries: Italy, Scotland and Belgium. HyTransit is another program sanctioned by EU, under which Van Hool and Ballard will supply 6 fuel cell buses to City of Aberdeen, Scotland, similar in design to High V.LO City buses. These projects aim to create a network of successful fuel cell bus operation sites, so called Clean Hydrogen Bus Centres of Excellence (CHBCE), linking High V.LO-City sites with similar fuel cell bus demonstrations in Europe. Both the High V.LO City and HyTransit projects are supported through the EU's JTI program.

In Canada, BC Transit has operated a fleet of 20 New Flyer buses with Ballard fuel cells that were deployed in time for the 2010 Winter Olympics. This fleet operates as the backbone of the transit service in the Resort Municipality of Whistler and has surpassed 1.9 million revenue miles [8]. It continues to be the largest fuel cell fleet to operate in a single location at one time. It also requires the largest hydrogen fueling station in the world to provide the fuel for the fleet with a dispensing capacity of 1000 kg day^{-1}. The hydrogen is shipped and stored in liquid form and dispensed into the demonstration fleet in a gaseous state.

In Japan, HINO (Toyota's bus subsidiary and the only fuel cell bus player) is operating 6 FCEBs with 90-kW Toyota fuel cells in various locations [9]. These buses were first deployed in 2005 as shuttles at the Aichi Expo. Although Toyota is one of the automakers most committed to light duty fuel cell vehicles, interest in the bus market is unclear.

In Korea, the situation is similar to Japan. Hyundai is the key fuel cell/OEM player. Hyundai is committed to commercial light duty fuel cell vehicles by 2014, but plans for buses are unclear. A Hyundai 40-ft bus with Hyundai 160 kW fuel cell has operated since 2006 in routine service in Seoul and Jeju island. Hyundai has a contract with Seoul to start supplying multiple FCEBs starting in 2013 [10].

In China, since 2005 FCEBs have been deployed for major events with global spotlight including 3 buses for the 2008 Summer Olympics and 6 for the 2010 Shanghai Expo [11]. In November and December 2010 a fleet of more than 50 fuel cell buses shuttled athletes and government officials to various venues of the Asian Games in Guangzhou City. These demo buses are no longer in service. In September 2013, Ballard announced a multi-year agreement to support Azure Hydrogen's fuel cell bus program for the Chinese market [12].

In Brazil and India, dozens of FCEBs with Ballard fuel cell are being planned for deployment within next few years [13,14].

This review article summarizes the performance data of FCEBs deployment globally, the status of fuel cell technology being used in FCEBs, the current hydrogen fueling infrastructure, and concludes with projections and targets for the next generation of FCEBs.