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Review

Prospects of fuel cell auxiliary power units in the civil markets☆

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Abstract

Auxiliary power units (APUs), i.e. devices designed to provide additional onboard power in vehicles, are believed to be an important entry point for fuel cell (FC) technology into commercial markets. Three technologies are under consideration for this market: solid oxide fuel cells (SOFCs), proton exchange membrane fuel cells (PEMFCs) and direct methanol fuel cells (DMFCs). By using the concept of total addressable, potential and capturable markets, this paper discusses the opportunities and challenges of fuel cell auxiliary power units (FC APUs). A number of conclusions can be drawn. As FC APUs do not offer increased fuel efficiency when meeting electrical demand while the main engine is used for propulsion (as opposed to idling), applications on board transit vehicles such as buses seem limited. Potential markets begin to open up in vehicles that either have a very large electricity demand due to many high-energy onboard functions, such as luxury limousines, or that require electrical power whilst stationary. Examples in the latter category include law enforcement vehicles, recreational vehicles, and most importantly heavy duty trucks. Volume and start-up time seem to be the major technical challenges hindering the market penetration of FC APUs. However, whilst the functional benefits of FC APUs over existing technologies are limited, the former must also be able to compete on a cost basis. The intense activities of APU manufacturers suggest a confidence either in the potential for cost reductions or in the consumers' willingness to pay. Similarly, the involvement of a number of big truck manufacturers casts doubt on the extent to which incumbents are taken by surprise by competence-destroying, disruptive and radical technologies like FC APUs.

Keywords: Auxiliary power units; Fuel cells; Commercialisation; Niche markets

Contents

☆ This article has greatly benefited from the discussion with the participants of the Workshop "Market and Technologies for Portable and APU Fuel Cells" (held on the 12 April 2006 at PSI). The discussion has been recorded in Hughes [7].

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1. Introduction

Auxiliary power units (APUs) are considered one of the early applications for fuel cells (FCs). Rather than replacing the main internal combustion engine (ICE) as a source of propulsion, in this market FCs would provide power and heat for onboard services, such as entertainment, heating, air conditioning and so on. APUs can improve generation efficiency, reduce emissions, extend the engine life and eliminate noise if power is needed when vehicles are parked. APU applications are attractive because they do not require FCs to compete with low-cost ICEs [1]. Three FC technologies are competing for APU applications: proton exchange membrane fuel cells (PEMFCs), solid oxide fuel cells (SOFCs) and direct methanol. Because of their operation at lower temperatures, PEMFCs benefit from a shorter start-up period and better load following. However, they are intolerant of carbon monoxide (CO) and sulphur. This implies that PEMFCs which do not run on pure hydrogen will require gas clean-up systems and low- or zero-sulphur fuel, because the platinum used as a catalyst is easily poisoned [2]. Reformers which supply pure hydrogen to the PEMFCs [3] decrease energy efficiency and increase the complexity, weight, volume and cost. If operating on hydrogen, PEMFCs require an effective storage system. SOFCs are designed in a planar and tubular geometry, the latter being at the refined prototype stage and the former only at the R&D stage. Another variation presents a thin film configuration design which exploits mature, cost-effective electronic-industry-based thin film fabrication processes [4]. Planar designs seem to offer high cost reduction when mass-manufactured and have the potential to provide higher power densities [5]. The high temperatures at which SOFCs operate, somewhere between 700 and 1000 °C [2,6], require the use of expensive materials, although they do not use the noble metals employed in PEMFCs [3]. Start-up time is about 1 h. SOFCs have the advantage of being able to use a variety of hydrocarbons through simple reforming processes, as fuels can be reformed in the cell, i.e. "internally". In addition, SOFCs have less stringent requirements about the hydrogen used as a fuel, they are less sensitive to sulphur and do not suffer from CO poisoning [6]. SOFCs neither need any complicated water management [3, p. 2] nor any external water supply, as the water needed by the cell can be provided by condensation of the exhaust [8,1].

Like the PEMFCs, the third type of FCs, i.e. DMFCs, use a polymer membrane as the electrolyte. Similarly to the SOFCs, a fuel reformer is not needed as a catalyst, normally platinum, draws hydrogen from liquid methanol. Platinum/ruthenium materials have been shown to possess higher intrinsic activity rates than platinum alone [9]. DMFCs can be divided into passive, where the water needed at the anode flows with the fuels, and active, where the water is collected from the cathode and pumped back to the anode by micro-pumps and micro-pipes which increase the size, complexity and cost of the system. The performance of DMFCs is normally impaired by methanol crossover, i.e. permeation of methanol through the membrane, which in the passive systems is reduced by carrying water together with the fuel. However, the most promising prototypes from Toshiba and MTIMicro use undiluted methanol—see [10] for a discussion. Some authors consider SOFCs as the clear winner over PEMFCs in APU applications [1,3,8]. Lamp et al. [6] believe that only SOFCs can reach the size and power required by APUs in the automotive market when gasoline is used as fuel. PEMFCs are likely to exceed the available package space because of the systems needed for gas purification, water management and cooling. Some authors consider PEMFCs as the main candidate [2]. Others conclude that SOFCs fuelled by diesel will be used on-board long-haul trucks and refrigerated trailer units while PEMFCs running on hydrogen will be used on-board law enforcement vehicles [11]. However, the only product currently in the market is based on a DMFC—see below.

This paper focuses on the market prospects of FCs used on-board road vehicles. These are not the only markets either for APUs or, more generally, for medium-sized FCs. Among the markets for the former one can mention leisure yachts [12], aeroplanes [13] and other aerospace craft [14]. Other interesting markets for medium-sized FCs are scooters and motorbikes [15,16], wheelchairs, forklift and golf-cart-like vehicles [17]. Reviews and discussions of these markets can be found in [18] and in the annual surveys published by Fuel Cell Today (see for example [19,20]). Military application is another very interesting market. The United States Army in conjunction with government, academia, national laboratories and the FCs industry is actively pursuing the development of FCs. The Army has selected PMFCs and DMFCs as the leading near-term technologies, although it demands the use of diesel, JP-8, and other logistics fuels[1] [21]. FC APUs are particularly useful to soldiers in "Silent Watch" settings, i.e. a tactical mode of operation demanding full electrical power for all mission activities, except mobility, without acoustic and infrared signature. Although one can argue that the size of the army market is limited [7], its importance in the diffusion of new technologies should not be underestimated. In many instances military technologies have spilled over into civilian markets, as the technology improves and prices fall. Military markets are, however, difficult to assess due to the lack of data in the public domain—see [22] for a necessarily cursory discussion. Despite the focus of this paper being firmly on APUs in the automotive market, the reader should bear in mind that there are a number of other interesting applications being tested and that new applications for FCs continue to open up, a point also discussed in Hughes [7].

The paper is structured as follows. Section 2 draws a qualitative judgement on the size of the markets by evaluating the benefits of FC APUs in a number of applications. Clearly the depth of this exercise is very influenced by the availability of

[1] R&D carried out in the Army aims at levels of reliability of FC APUs much higher than those normally required in the civil market. On the other hand, civil consumers are likely to be more price-sensitive than military consumers. The volume or weight of products delivered to the Army may also not be particularly appealing to civil consumers. In other words, although the FC APUs delivered to the Army will meet the reliability standards of the average civil consumer, it is not entirely clear whether civil consumers will be ready to adopt those products because of price, volume and weight specifications