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Direct ethanol fuel cells for transport and stationary applications – A comprehensive review

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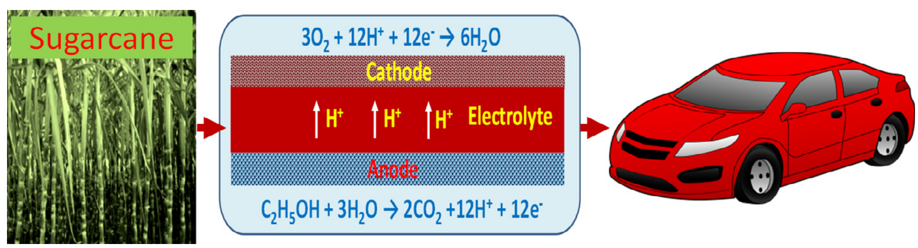
HIGHLIGHTS

- A comprehensive review of various direct ethanol fuel cells has been provided.
- Bio-ethanol sources and production processes have been discussed in detail.
- Fuel cells operating on bio-ethanol fuel offer economic and environmental advantages.
- Materials, operating regimes, performance and life time issues are discussed.
- The technology status and market applications have been detailed.

GRAPHICAL ABSTRACT



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ABSTRACT

Fuel cells are one of the most efficient means of converting chemical energy into electrical energy. The major deterrents to the commercialisation of fuel cell technologies, especially for the transport sector, are the hydrogen storage and almost non-existence of hydrogen transportation and distribution infrastructure. The utilisation of bio-fuels such as methanol and ethanol instead of hydrogen as a fuel in fuel cells, not only reduces issues with fuel transportation and storage, but can also provide a CO_2 neutral power generation technology and lead to a reduction in CO_2 and other pollutants. In particular bioethanol is attractive as it is non-toxic, inexpensive, renewable and readily available. Currently around 90 billion litres per annum of ethanol is produced globally. It can be produced from a range of feedstock which includes sugar-cane, wheat, corn and low grade biomass such as woodchips, bagasse, waste from agro-industries, organic fractions from municipal waste or forestry residue. These factors make ethanol, especially when used with a low emission technology such as fuel cells, attractive from both an economic and environmental perspective. This has lead to a considerable interest in developing fuel cell systems operating directly on bioethanol. In this paper various types of direct ethanol fuel cells currently under development have been reviewed with emphasis on ethanol sources and production methods, cell construction materials, operating regime, cell and stack fabrication, performance and life time issues, technology status and market applications.

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Contents

1. Introduction

In general, fuel cells are known to have significantly higher fuel conversion and electrical efficiencies than conventional combustion or power generation technologies and produce far fewer toxic emissions such as NOx, ozone and particulates [1–3]. These combined with their modularity, low noise levels, high fuel utilisation rates, combined heat and power generation capability at end-use sites and lower greenhouse gas emissions make fuel cells an attractive option for future transport, stationary and portable power applications with significant long term economic and environmental benefits.

Apart from high cost and life time issues, the major deterrents to the commercialisation of fuel cell technologies, especially for the transport sector, are the availability of cost effective hydrogen storage technologies and almost non-existence of the hydrogen transportation and distribution infrastructure. The utilisation of liquid fuels such as ethanol and methanol in fuel cells would reduce the requirements of establishing totally new infrastructure as required for hydrogen as a fuel source. Especially the infrastructure and supply chain for ethanol as a transport fuel is already in existence or can be easily modified. Bioethanol either in hydrous form or blended with gasoline is used as a fuel for transport in many countries with Brazil well known for its policy on the bioethanol production and use in transport vehicles [4–6]. Furthermore, both methanol and ethanol are renewable fuels when generated from biomass sources although currently bioethanol dominates the global bio-fuel production capacity. Thus the use of bio-fuels as a source of fuel in fuel cells would not only offer ease of transportation and storage, but would also provide a CO_2 neutral power generation technology, and overall reduction in CO_2 and other pollutants [4,5]. With dwindling petroleum reserves and forecast indicating peak in oil production in the next few years, bio-fuels also provide regional security for transport fuels.

The feedstock for producing bioethanol includes sugarcane, corn, beetroot, wheat, soybean, or even low grade widely available cellulose containing organic matter (cellulosic ethanol) such as biomass, woodchips, bagasse, waste from agro-industries, organic fractions from municipal waste or forestry residue [4,6–10]. The two largest producers of bioethanol are USA and Brazil, accounting for ~87% of global ethanol production of ~85 billion litres in 2011 [6] with ~62% produced in the USA and ~25% in Brazil. Over 40% of transport fuel consumption in Brazil has been substituted by bioethanol produced mainly from sugarcane. In the USA bioethanol, produced mainly from corn crop, accounts for 10% of USA transport fuel supply [4–6]. Although, bioethanol can be easily produced from food crops such as sugarcane and corn by fermentation, there is a widespread concern about this process of fuel production competing with the food supply chain and the energy required to grow crops versus the energy output from the fuel so produced. Although different studies report varying output to input energy ratios, bioethanol produced from sugarcane has significantly more favourable output to input energy ratio compared to corn (~8 versus ~2) depending on how co-products are utilised [7,8]. However, the production of ethanol from non-edible lignocellulosic biomass feedstock such as food crop and forest residues, industrial waste, and grasses or trees grown specifically for this purpose, is gaining momentum [4,9,10].

In terms of alcohol based fuel cells, there has been substantial effort in developing both direct (methanol consumed directly in electrochemical reactions) and indirect methanol (where methanol is converted to hydrogen fuel which is then consumed in a normal