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An overview of fuel cell technology: Fundamentals and applications

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ABSTRACT

This paper provides a comprehensive review of fuel cell science and engineering with a focus on hydrogen fuel cells. The paper provides a concise, up-to-date review of fuel cell fundamentals; history; competing technologies; types; advantages and challenges; portable, stationary, and transportation applications and markets; current status of research-and-development; future targets; design levels; thermodynamic and electrochemical principles; system evaluation factors; and prospects and outlook. The most current data from industry and academia have been used with the relation between fuel cell fundamentals and applications highlighted throughout the manuscript.

Contents

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Abbreviations

AFC	alkaline fuel cell
APU	auxiliary power unit
BoP	balance of plant
CCHP	combined cooling, heating, and power
CHP	combined-heat-and-power
DMFC	direct methanol fuel cell
EPS	emergency back-up power supply
FCEB	fuel cell electric bus
FCEV	fuel cell electric vehicle
GDL	gas diffusion layer
GHG	greenhouse gas
H-FCEV	heavy-duty fuel cell electric vehicle
HHV	higher heating value
L-BEV	light-duty battery electric vehicle
L-FCEV	light-duty fuel cell electric vehicle
LHV	lower heating value
LPG	liquefied petroleum gas
LTV	light traction vehicle
MCFC	molten carbonate fuel cell
MEA	membrane electrode assembly
PAFC	phosphoric acid fuel cell
PEMFC	polymer electrolyte membrane fuel cell
PGM	platinum group metals
PV	photovoltaic
RAPS	remote-area power supply
SOFC	solid oxide fuel cell
UAV	unmanned aerial vehicle

1. Introduction

A fuel cell is an electrochemical device that converts the chemical energy of a fuel directly into electrical energy. The one-step (from chemical to electrical energy) nature of this process, in comparison to the multi-step (e.g. from chemical to thermal to mechanical to electrical energy) processes involved in combustion-based heat engines, offers several unique advantages. For instance, the current combustion-based energy generation technologies are very harmful to the environment and are predominantly contributing to many global concerns, such as climate change, ozone layer depletion, acidic rains, and thus, the consistent reduction in the vegetation cover. Furthermore, these technologies depend on the finite and dwindling world supplies of fossil fuels.

Fuel cells, on the other hand, provide an efficient and clean mechanism for energy conversion. Additionally, fuel cells are compatible with renewable sources and modern energy carriers (i.e., hydrogen) for sustainable development and energy security. As a result, they are regarded as the energy conversion devices of the future. The static nature of fuel cells also means quiet operation without noise or vibration, while their inherent modularity allows for simple construction and a diverse range of applications in portable, stationary, and transportation power generation. In short, fuel cells provide a cleaner, more efficient, and possibly the most flexible chemical-to-electrical energy conversion.

Polymer electrolyte membrane, also proton exchange membrane, fuel cells (PEMFC) in particular are one of the most promising types already in the early commercialization stage. Nonetheless, further development and research are required in order to reduce their costs, enhance their durability, and further optimize and improve their performance. Most of the research currently being conducted on PEMFCs is on the individual cell-level and the general system-level. Stack-level research, on the other hand, is an area that requires further research and development.

A proper understanding of the principles of fuel cell operation combined with a current outlook of the fuel cell industry are vital for overcoming current obstacles and the general advancement of fuel cell technology. Nevertheless, fuel cells are an interdisciplinary science in which electrochemistry, thermodynamics, engineering economics, material science and engineering, and electrical engineering all combine; making this a difficult task. This paper provides an up-to-date overlook of the fuel cell industry coupled with a concise digest of fuel cell operation principles as a contribution to the ongoing efforts to promote and commercialize fuel cells. We will often attempt to highlight the relations between a fuel cell's principals of operation, features and advantages, and areas of applications throughout the manuscript. This relation between principals, features, and applications is outlined in Fig. 1.

2. An overview of fundamentals

A fuel cell is composed of three active components: a fuel electrode (anode), an oxidant electrode (cathode), and an electrolyte sandwiched between them. The electrodes consist of a porous