

Accepted Manuscript

Review

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PII: S2095-8099(17)30775-0

DOI: <https://doi.org/10.1016/j.eng.2018.05.007>

Reference: ENG 72

To appear in: *Engineering*

Received Date: 3 December 2017

Revised Date: 31 January 2018

Accepted Date: 15 May 2018

Please cite this article as: J. Wang, H. Wang, Y. Fan, Techno-Economic Challenges of Fuel Cell Commercialization, *Engineering* (2018), doi: <https://doi.org/10.1016/j.eng.2018.05.007>

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Research
Green Industrial Processes—Review

Techno-Economic Challenges of Fuel Cell Commercialization

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ARTICLE INFO

Article history:

Received 3 December 2017

Revised 31 January 2018

Accepted 15 May 2018

Available online

Keywords:

Energy security

Fuel cells

Cost analysis

Durability and reliability

Energy storage

ABSTRACT

As resource scarcity, extreme climate change, and pollution levels increase, economic growth must rely on more environmentally friendly and efficient production processes. Fuel cells are an ideal alternative to internal combustion (IC) engines and boilers on the path to greener industries because of their high efficiency and environmentally friendly operation. However, as a new energy technology, significant market penetration of fuel cells has not yet been achieved. In this paper, we perform a techno-economic and environmental analysis of fuel cell systems using life cycle and value chain activities. First, we investigate the procedure of fuel cell development and identify what activities should be undertaken according to fuel cell life cycle activities, value chain activities, and end-user acceptance criteria. Next, we present a unified learning of the institutional barriers in fuel cell commercialization. The primary end-user acceptance criteria are function, cost, and reliability; a fuel cell should outperform these criteria compared with its competitors, such as IC engines and batteries, to achieve a competitive advantage. The repair and maintenance costs of fuel cells (due to low reliability) can lead to a substantial cost increase and decrease in availability, which are the major factors for end-user acceptance. The fuel cell industry must face the challenge of how to overcome this reliability barrier. This paper provides a deeper insight into our work over the years on the main barriers to fuel cell commercialization, and discusses the potential pivotal role of fuel cells in a future low-carbon green economy. It also identifies the needs and points out some directions for this future low-carbon economy. Green energy, supplied with fuel cells, is truly the business mode of the future. Striving for a more sustainable development of economic growth by adopting green public investments and implementing policy initiatives encourages environmentally responsible industrial investments.

1. Introduction

As the world population grows and fossil fuel energy supplies gradually decline, the world's energy supply may not meet the increasing demands or sustainable environmental targets. Therefore, there is an increasing need to ensure future energy security and a sustainable environment in many countries. Energy security is defined as "the uninterrupted availability of energy sources at an affordable price" by the International Energy Agency (IEA) [1]. Many countries have made efforts to develop a low-carbon economy and green industries as long-term objectives in order to ensure an energy supply that aligns with their economic development and sustainable environment goals [2,3]. There are two ways to achieve a low-carbon economy: One is to increase the share of green energy to meet increasing energy demands, and mitigate greenhouse gas (GHG) emissions by reducing fossil fuel dependency; the other is to save energy and reduce emissions by increasing the efficiency of existing energy systems.

The substantial development and integration of renewable energy can lead to a low-carbon green economy and to new business opportunities. A wide range of renewable resources have been developed such as wind energy, solar energy, bioenergy, and tidal energy [4–6]. While every type of renewable energy has its advantages and disadvantages, combining them with existing fossil fuel systems increases the complexity of managing energy systems and the difficulty for governments to direct policy and investment. Therefore, analysis of any single type of energy system alone is no longer sufficient in order to understand a country's energy security needs and future energy direction as a whole; rather, a systematic and rigorous understanding of a wider range of energy availability and diversity is required. In most countries,

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